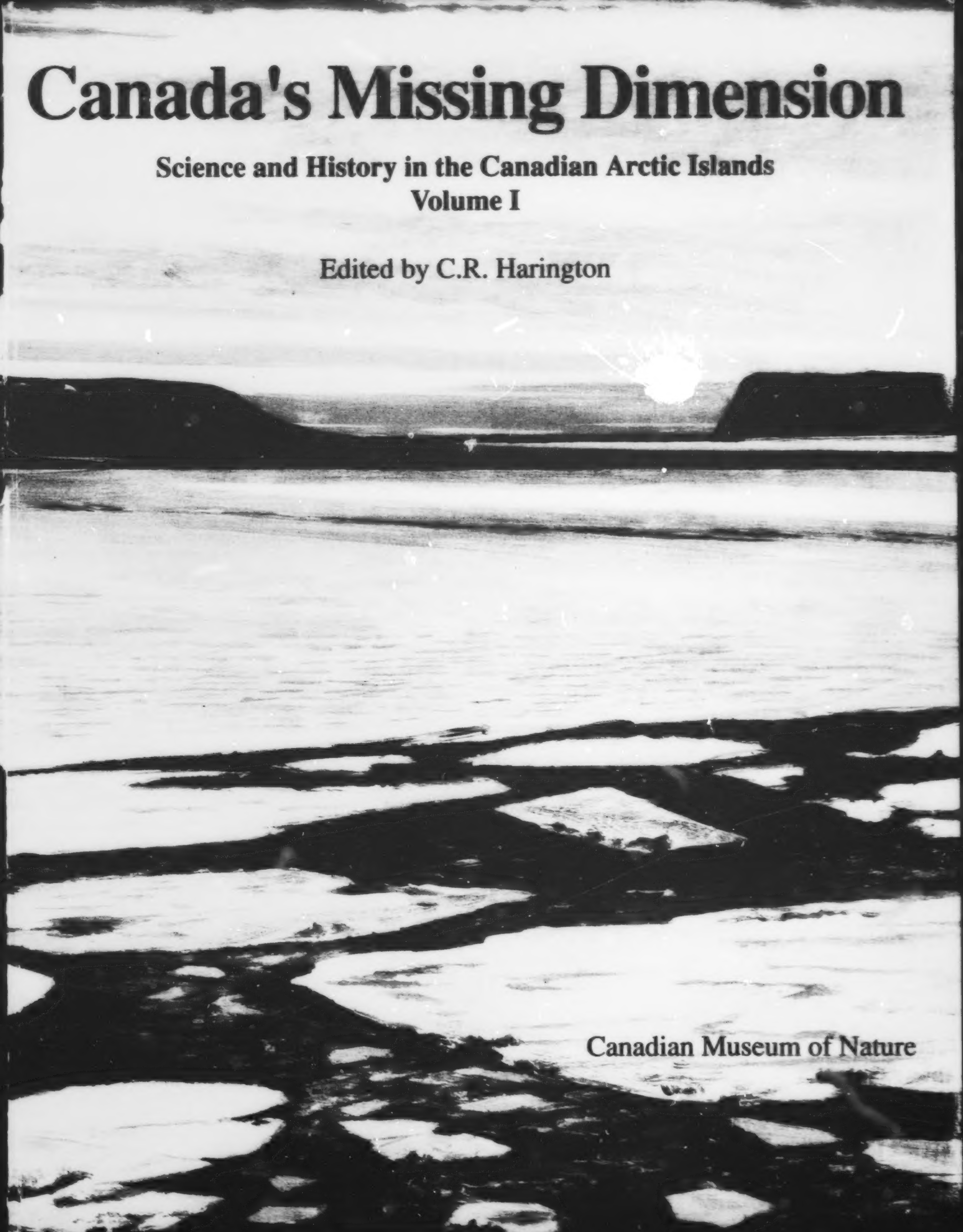
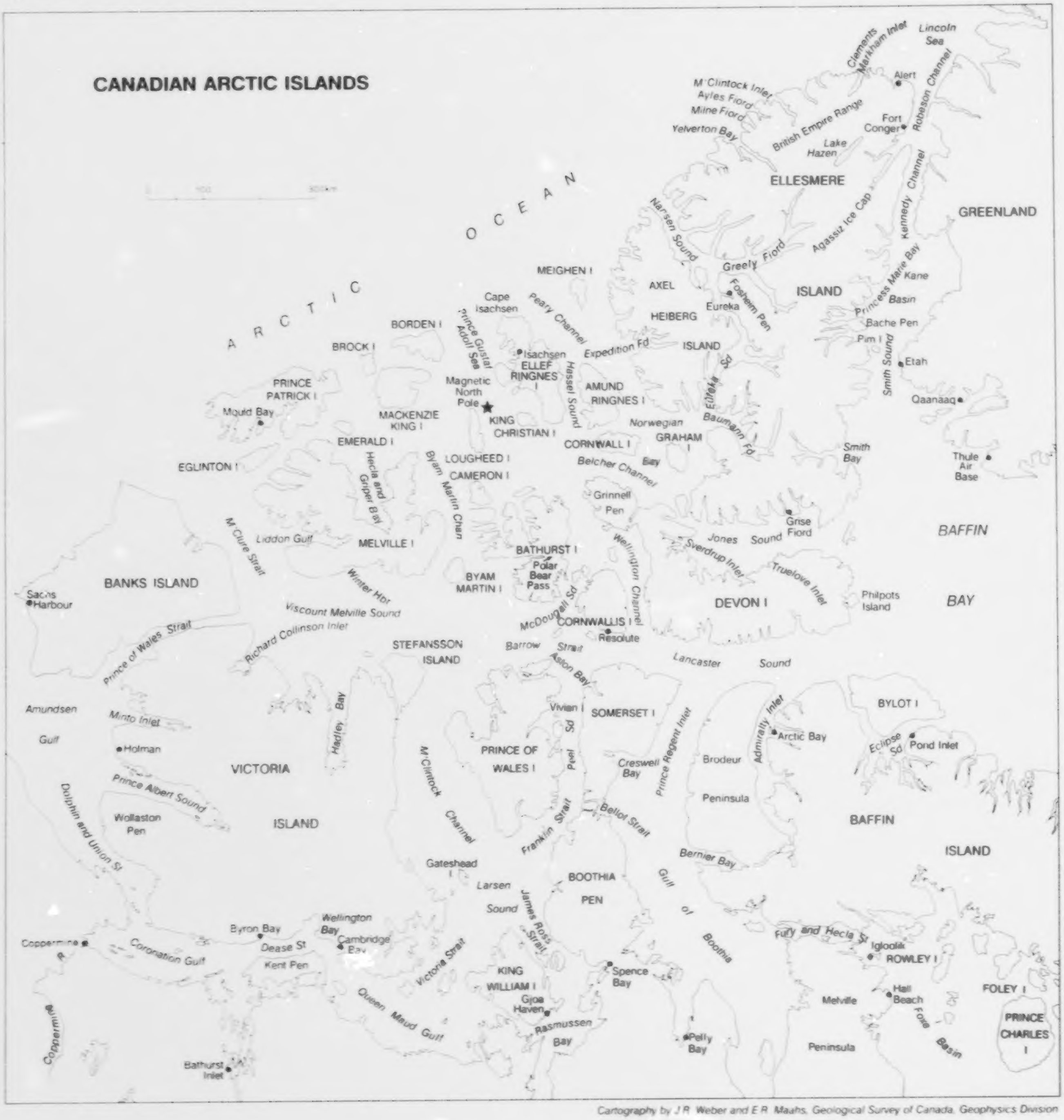


Canada's Missing Dimension

Science and History in the Canadian Arctic Islands
Volume I

Edited by C.R. Harington

Canadian Museum of Nature



CANADIAN ARCTIC ISLANDS

ARCTIC OCEAN
Lincoln Sea
Clements Markham Inlet
Robeson Channel
Alert
M'Clintock Inlet
Ayles Fiord
Milne Fiord
Yelverton Bay
British Empire Range
Fort Conger
Lake Hazen
ELLESMERE
ISLAND
Kennedy Channel
GREENLAND
Nansen Sound
Agassiz Ice Cap
Greely Fiord
Princess Marie Bay
Kane Basin
Fosheim Pen
Eureka
AXEL
HEIBERG
ISLAND
MEIGHEN I
Cape Isachsen
Peary Channel
Bache Pen
Pim I
Etah
Smith Sound
Qaanaaq
BORDEN I
Prince Gustaf Adolf Sea
Isachsen
ELLEF RINGNES I
Expedition Fd
Eureka Sd
BROCK I
PRINCE PATRICK I
Magnetic North Pole
Hassel Sound
AMUND RINGNES I
Mould Bay
MACKENZIE KING I
KING CHRISTIAN I
Norwegian Bay
Baumann Fd
EMERALD I
CORNWALL I
GRAHAM I
Smith Bay
Thule Air Base
EGLINTON I
Hecla and Griper Bay
Byam Martin Chan
LOUGHEED I
CAMERON I
Belcher Channel
Grinnell Pen
M'Clure Strait
Liddon Gulf
MELVILLE I
BATHURST I
Wellington Channel
Jones Sound
Grise Fiord
Sverdrup Inlet
BAFFIN
BAY
BANKS ISLAND
Sachs Harbour
Winter Hbr
BYAM MARTIN I
Polar Bear Pass
Truelove Inlet
Viscount Melville Sound
McDougall Sd
CORNWALLIS I
DEVON I
Philpots Island
Resolute
Prince of Wales Strait
Richard Collinson Inlet
STEFANSSON ISLAND
Barrow Strait
Lancaster Sound
Aston Bay
Amundsen Gulf
Minto Inlet
Hadley Bay
Vivian I
SOMERSET I
Prince Regent Inlet
Admiralty Inlet
BYLOT I
Arctic Bay
Eclipse Sd
Pond Inlet
Holman
VICTORIA
ISLAND
M'Clintock Channel
PRINCE OF WALES I
Peel Sd
Creswell Bay
Brodeur Peninsula
Prince Albert Sound
Wollaston Pen
Dolphin and Union St
Franklin Strait
Bellot Strait
BAFFIN
ISLAND
Bernier Bay
Gateshead I
Larsen Sound
BOOTHIA PEN
Gulf of Boothia
James Ross Strait
Byron Bay
Wellington Bay
Cambridge Bay
Dease St
Kent Pen
Coppermine
Coronation Gulf
Victoria Strait
Fury and Hecla St
Igloolik
ROWLEY I
KING WILLIAM I
Spence Bay
Gjoa Haven
Hall Beach
Melville Peninsula
Foxe Basin
FOLEY I
PRINCE CHARLES I
Queen Maud Gulf
Rasmussen Bay
Pelly Bay
Coppermine R
Bathurst Inlet

Cartography by J.R. Weber and E.R. Maahs, Geological Survey of Canada, Geophysics Division

Canada's Missing Dimension

Science and History in the Canadian Arctic Islands
Volume I

Edited by C.R. Harington

Published by: Canadian Museum of Nature

Shell Canada Limited

Petro-Canada Inc.

Polar Continental Shelf Project

93-02400/

© 1990 Canadian Museum of Nature

Published by the:

Canadian Museum of Nature
Ottawa, Canada K1P 6P4

Catalogue No. NM98-13/2-1990E

Available by mail order from:

Canadian Museum of Nature
Direct Mail Section
P.O. Box 3443, Station "D"
Ottawa, Canada K1P 6P4

Printed in Canada

ISBN: 0-660-13054-8

Cover: Cape Clarence, Somerset Island
Painting by Brenda Carter, Merrickville, Ontario

Brenda Carter sketches: title page, pages 21, 40, 53, 54, 90, 104, 130, 152, 160, 186, 254, 258, 271, 272, 293, 326, 404, 420, 441, 442, 470, 510, 513, 543, 567, 589, 607, 632, 664, 676, 694, 742, 767, 792, 805, 834

© 1990 Musée canadien de la nature

Publié par le :

Musée canadien de la nature
Ottawa, Canada K1P 6P4

No de catalogue NM98-13/2-1990E

L'editeur remplit les commandes postales adressées au :

Musée canadien de la nature
Section des commandes postales
C.P. 3443, Succursale D
Ottawa, Canada K1P 6P4

Imprimé au Canada

ISBN: 0-660-13054-8

Peinture de la couverture : Cap Clarence, Île Somerset, de Brenda Carter (Merrickville, Ontario)

Esquisses de Brenda Carter : page titre, p. 21, 40, 53, 54, 90, 104, 130, 152, 160, 186, 254, 258, 271, 272, 293, 326, 404, 420, 441, 442, 470, 510, 513, 543, 567, 589, 607, 632, 664, 676, 694, 742, 767, 792, 805, 834

ACKNOWLEDGEMENTS

I am grateful to my colleagues on the Organizing Committee of the international meeting ("The Canadian Arctic Islands: Canada's Missing Dimension", Ottawa, November 21-24, 1987), from which this volume arose: Dr. John S. Tener - General Chairman, Dr. S.L. Cumbaa - Directorate Liaison, Mrs. Gail Rice - Secretary-Treasurer, and Mr. Clayton Kennedy - Coordinator, Poster Presentations. I thank Dr. Alan R. Emery, director of the museum for his interest in and encouragement of the project.

I particularly acknowledge prompt, substantial and practical support for word processing the first draft of the book by **Polar Continental Shelf Project** (Pierre Lapointe, Director; George D. Hobson - Special Advisor; and Jackie Voyce - Secretary to the Director). Substantial funding for the book came from:

Shell Canada Limited
and
Petro-Canada Inc.

Gail Rice (Assistant to the Division Chief, Paleobiology Division) in addition to her invaluable assistance in organizing the meeting, helped greatly in preparation of this book. Also, I am grateful to Audrey Sirois for her care in word-processing the manuscript, and to Arch Stewart (Library Services, National Museum of Natural Sciences) for helping to check many references. Dr. Bernard Lauriol and Daniel Lagarec (Department of Geography, University of Ottawa) kindly helped to check the Résumés.

Brenda Carter, the well known nature artist, graciously allowed me to use her painting of Cape Clarence, Somerset Island, on the cover, and many of her northern field sketches throughout the book. I am grateful to Dr. J.R. Weber (Geophysics Division, Geological Survey of Canada), who arranged for the maps inside the covers and to Earl Maahs, head of the Graphics Office of that division, for producing them.

Finally, I would like to express my deep personal thanks to three people who have acted as trusted guides and counselors during my journey along the "White Road": Drs. William C. Wonders; Maxwell J. Dunbar; and John S. Tener.

C.R. Harington

CONTENTS

Volume I

ACKNOWLEDGEMENTS 1

INTRODUCTION 6

C.R. Harington

SCIENTIFIC RESEARCH: SUPPORT, CONFLICT AND THE FUTURE

Polar Continental Shelf Project 9
George D. Hobson

Conflict in Northern Activities 22
R.L. Christie

Scientific Research in the Canadian Arctic Islands - The Future 41
E.F. Roots

THE EARTH: FOSSILS AND PALEOENVIRONMENTS

Paleozoic Fishing - The Franklinian Grounds 55
D.L. Dineley

Mesozoic Vertebrates in Arctic Canada 81
Dale A. Russell

Terrestrial Vertebrates from the Tertiary of Canada's Arctic Islands 91
Mary R. Dawson

New Data on the Late Tertiary Beaufort Formation: Plant and Insect Fossils from Prince Patrick Island, N.W.T. 105
John V. Matthews, Jr., L.E. Ovenden, and J.G. Fyles

Ice Age Vertebrates in the Canadian Arctic Islands 140
C.R. Harington

Rates of Decay of Mammalian Remains in the Permafrost Environment of the Canadian High Arctic 161
Antony J. Sutcliffe

FRESHWATER, SEA AND ICE

A Unique Lake in Canada's High Arctic 188
M. Dickman, A.G. Lewkowicz, and J. Price

Ice/Water Interactions and Their Effect on Biological Oceanography in the Arctic Archipelago 204
Robert J. Conover, Glen F. Cota, W. Glen Harrison, Edward P.W. Horne, and Ralph E.H. Smith

Surface Topography, Thickness and Ice Core Studies of Multiyear Landfast Sea Ice and Ward Hunt Ice Shelf, Northern Ellesmere Island, N.W.T. 229
Martin O. Jeffries, H. Roy Krause, William M. Sackinger, and Harold V. Serson

Acoustic Research on Sounding through Sea Ice and Iceberg Detection in the Canadian Arctic 255
Phillipe de Heering

Arctic Ice Cores: Putting Present Climate into Perspective 265
Roy M. Koerner

THE ATMOSPHERE

Climate and the Canadian Arctic Islands 273
Gordon A. McKay

The Queen Elizabeth Islands: A Case Study for Arctic Climate Data Availability and Regional Climate Analysis 294
Bea Taylor Alt and Barrie Maxwell

L'Exposition des Plaques de Neige Résiduelles dans l'Arctique Canadien 327
Daniel Lagarec, Bernard Lauriol et Daniel Devocht

Arctic Meteorology and Climatology, Present State and Future Direction 337
Claude L. Labine

THE PLANTS

High Arctic Ecosystems: How They Develop and Are Maintained 350
L.C. Bliss

Lichens in the Canadian Arctic Islands 385
John W. Thomson

Bioclimatic Zones in the Canadian Arctic Archipelago 421
S.A. Edlund

Volume II

INSECTS

Arctic Insects: Instructive Diversity 444
H.V. Danks

Crane Flies (Diptera:Tipulidae) of the Arctic Islands 471
Fenja Brodo

Energy Budget for Activity and Growth of a High Arctic Insect, Gynaephora groenlandica (Wocke) (Lepidoptera:Lymantriidae) 485
Olga Kukal

FISHES, BIRDS AND MAMMALS

Priorities for Ichthyological Research in the Canadian Arctic Archipelago 512
Don E. McAllister

Avian Zoogeography in the Canadian Arctic Islands 516
Henri Ouellet

Migration, Body Condition and Behaviour of Shorebirds during Spring Migration at Alert, Ellesmere Island 544
R.I.G. Morrison and N.C. Davidson

Winter Studies of Birds and Mammals in the Canadian Arctic Islands 568
David R. Gray

The Decline and Recovery of Caribou and Muskoxen on Victoria Island 590
Anne Gunn

Inter-Island Movements of Peary Caribou: A Review and Appraisement of Their Ecological Importance 608
Frank L. Miller

Muskox (Ovibos moschatus Zimmermann) Populations on the Northeastern Coast of Devon Island 633
Donald L. Pattie

Some Observations on the Nursing Behaviour of Arctic Hares (Lepus arcticus) 643
B.T. Aniškowicz, H. Hamilton, D.R. Gray, and C. Downes

HUMAN PREHISTORY

The Peopling of the Arctic Islands 666
Robert McGhee

Thule Pioneers in the Canadian Arctic 677
Charles D. Arnold and Karen McCullough

Prehistoric Thule Eskimo Whaling in the Canadian Arctic Islands: Current Knowledge and Future Research Directions 695
James M. Savelle and Allen P. McCartney

Environmental and Cultural Change in the Large Lakes Region of Baffin Island: A Progress Report 724
J.D. Jacobs, D.R. Stenton, and W.N. Mode

HISTORY AND RECENT EXPEDITIONS

Discoveries and Explorations of the Circumpolar Lands and Seas from Antiquity to the Twentieth Century 744
J.R. Weber and E.F. Roots

Emile Frédéric de Bray and His Role in the Royal Navy's Search for Franklin, 1852-1854 768
William Barr

The 1983 Ellesmere Island Arctic Expedition 793
Tim O. Rockwell

Exploratory Mountaineering in the Arctic Islands 806
G.V.B. Cochran

INDEX 835

INTRODUCTION

The engine droned on and island after island passed beneath the wing: masses of ice coiled like necklaces on the dark waters of the straits separating them. Basking seals popped into their holes like billiard balls as we descended. Circles of whalebone houses appeared, as common as moon craters, on Brooman Point en route to the lush arctic oasis of Polar Bear Pass (the only place I have seen a band of Peary caribou calmly drifting through a herd of grazing muskoxen). It was during a 1961 aerial survey of muskoxen and caribou in the Queen Elizabeth Islands that I first got an inkling of the vastness and diversity of the Canadian Arctic Islands. From the bleak, flat apron of the Beaufort Formation in the west to the badlands of eastern Prince Patrick Island, the fortress-like cliffs of eastern Cornwallis Island and intervening flights of raised gravel beaches, to the ice-covered mountains of Ellesmere Island with its spectacular tidewater glaciers and fiords.

I wish all Canadians could not only see, but experience life in the Arctic Islands. Although these islands comprise about a fifth of the country, and are significant and intriguing in their own right, they are Canada's missing dimension. Nevertheless, perhaps a few people not familiar with this region will gain a clearer picture of science and history there by consulting this book, which stems from an international meeting ("The Canadian Arctic Islands: Canada's Missing Dimension", sponsored by the National Museum of Natural Sciences, Ottawa, November 21-24, 1987).

Contributors to the book were encouraged to: provide current coverage of knowledge about the region's natural heritage; place that knowledge in historical context with a view to the future; detect important gaps in our present understanding of natural processes and suggest ways of filling such gaps. The following papers include a large sample of those presented at the meeting plus some pertinent new contributions.

The book begins with general discussions on support for, conflict in, and the future of scientific research in the islands. Following this, various spheres of knowledge are considered in sequence: (1) the geosphere (fossils - mainly vertebrates - and paleoenvironments); (2) the "hydro-cryosphere" (freshwater, sea and ice); (3) the atmosphere; (4) the biosphere (living plants, insects, fishes, birds and mammals other than people); and (5) the "anthroposphere" (human prehistory, history and recent expeditions). In some cases, the sections begin with general papers that will help readers gain perspective on the more specialized contributions - several of which will interest mainly experts. A natural transition between geosphere and "anthroposphere" sections occurs in A.J. Sutcliffe's paper.

This publication is intended for those who are deeply interested in nature, history and the Canadian Arctic Islands. It may be a handy milestone on our road to revealing the "True North" - perhaps complementing another recent Arctic Islands symposium volume (Zaslow 1981), which focuses more on the history of various disciplines, policy, strategy, sociology and economics.

A personal highlight resulting from attending the meeting and reading the papers was the potent combination of R.J. Conover and others' discourse on sea ice and its relation to biological oceanography with the National Film Board's "Edge of Ice" introduced by M.J. Dunbar. The paper and film revealed a whole new upside-down world! While caribou, muskoxen, polar bears and humans use the frozen, windswept top of the sea ice as a bridge between islands or a hunting platform, there is a mellower, bottle-green world below: its faulted hills and valleys being the hummocky underside of the ice torn by bright leads. There, zooplankton graze like flocks of tiny sheep on greenish-brown fields of algae; and seals, like streamlined airships glide freely in three dimensions, navigating by the underice topography.

Several waves of human occupation have lapped the islands' shores over the last 4,000 years. Of these, the Thule people seem to have been most in tune with the environment. But even they were severely challenged by the deteriorating climate of the Little Ice Age - as were their Norse brothers, who apparently penetrated the eastern part of the region before their colonies in Greenland died out. During the last 400 years, Euro-American exploration using large ships and man-hauled sleds (surprisingly effective in a few cases), as well as Inuit-style dog-sleds, has led to the present situation. Now, settlements of Inuit and whites decrease in number and size northward to a handful of scattered weather/military bases like Alert that are serviced by aircraft or ice-breaking ships. Another characteristic is the bloom of fanatical scientists that flood the islands each summer, only to disappear during the most critical period for survival of the land biota!

Another impression I am left with is that this region has changed remarkably with time: from virtual tropical conditions in the Siluro-Devonian to arctic at present (only about 10,000 years ago most of the islands were covered by ice). Landscapes, plantscapes and animals changed in lingering harmony with the restless climate. What will the future bring?

How can we try to overcome the weaknesses in our knowledge of the Arctic Islands and begin filling the gaps so diligently indicated by contributors to this book? Why not establish several long-term, year-round "nature observatories" at inland as well as coastal sites and polynyas across the islands ...like a scientific DEW Line? They could focus on weather and climate as they affect biota (e.g. covering variations in aquatic primary productivity, plant productivity on land and swings in animal populations). Such observatories, fed by remote-sensing and automatic weather station data, would not only provide the earliest, most sensitive practical information on the biotic impact of the "greenhouse" warming predicted for the near future (should it occur), but would yield valuable insights into the long-term operation of arctic ecosystems. Such a move would strengthen Canada's claim to sovereignty in the region while developing arctic scientific expertise among northern native and other Canadian students. The essence of this proposal has been made many times (Hattersley-Smith 1982): perhaps, finally, it is time for action!

C.R. Harington, Editor

REFERENCES

Zaslow, M. (Editor). 1981. A century of Canada's Arctic Islands. The Royal Society of Canada, Ottawa. 358 pp.

Hattersley-Smith, G. 1982. Review of: "A Century of Canada's Arctic Islands". Arctic 35(4):565-566.

SCIENTIFIC RESEARCH: SUPPORT, CONFLICT AND THE FUTURE

POLAR CONTINENTAL SHELF PROJECT

George D. Hobson[1]

Abstract: The Polar Continental Shelf Project (PCSP) was initiated by Cabinet Memorandum in 1958 shortly after Sputnik was launched by the U.S.S.R. PCSP conducts studies of scientific problems unique to the Canadian Arctic, and provides vital logistical support and advice to other scientific research groups working in the Canadian Arctic Islands and the Arctic Ocean. These logistics include equipment, a radio network, aircraft, base-camps at Tuktoyaktuk and Resolute - all the essential support to put scientists in the field, maintain them there safely while they collect data, and get them home again. It cooperates with government departments and agencies and with universities in providing expertise and facilities for their studies, and keeps both the scientific community and Arctic residents informed of continuing scientific operations. Visits to the settlements were begun in 1974 as a means of informing the native peoples about the science that was going on in their backyards; for years PCSP was the only contact some of the settlements had with scientists. PCSP's multidisciplinary, interdepartmental, interagency character continues to be instrumental in fostering effective and economical scientific development of the Canadian Arctic.

Résumé: L'étude du plateau continental polaire (EPCP) a été établie par mémoire du Cabinet en 1958, peu après le lancement de Spoutnik par l'URSS. L'EPCP étudie les problèmes scientifiques propres à l'Arctique canadien, et fournit les conseils et le soutien logistique essentiels aux autres groupes de recherche scientifique oeuvrant dans les îles de l'Arctique canadien et dans l'océan Arctique. Ce soutien logistique comprend de l'équipement, un réseau radio, des avions, des camps de base à Resolute et à Tuktyaktuk - tout ce qui est nécessaire pour amener les scientifiques sur le terrain, les y garder en sécurité pendant qu'ils y recueillent des données, et finalement les rapatrier. Elle collabore avec des ministères et organismes gouvernementaux, et avec des universités, auxquels elle fournit l'expertise et les installations indispensables à leurs études, et tient tant la communauté scientifique que les résidents de l'Arctique informés des opérations scientifiques en cours. En 1974, on a commencé à rendre visite aux communautés autochtones pour les tenir au courant des études scientifiques qui se déroulaient sur leur territoire; pendant des années, ce fut pour certaines leur seul contact avec des scientifiques. Le caractère pluridisciplinaire, interministériel et inter-organismes de l'EPCP demeure essentiel pour un développement scientifique efficace et économique dans l'Arctique canadien.

POLAR CONTINENTAL SHELF PROJECT

Of 40 papers presented at this international meeting on the Canadian Arctic Islands (many of which are included in this volume), only five were not supported by Polar Shelf. I am literally preaching to the converted. What can I say about Polar Shelf to such a group? First, I want to say something about its history, since many people do not know its background. I will also attempt to provide insight into how I feel about science in the North, and then I would like to mention something that is coming along. It is actually here now, but most of us have a tendency to ignore the land-claim settlements.

The Polar Continental Shelf Project (PCSP) was organized by the Advisory Committee on Northern Development (ACND). At present, that committee is moribund, but at one time it was very active. Some people attending this meeting, such as Jim Harrison, Graham Rowley and Keith Greenaway had talked about a Polar Continental Shelf Project for several years. They are the godfathers of the PCSP. By 1958, when a Memorandum to Cabinet was presented, these gentlemen, as members of the ACND, considered that the time had come for such a project. Although they were not pushed into the decision, they had a certain amount of assistance. Sputnik first flew in 1957. Also in 1958, the Law of the Sea Conference in Geneva stated that maritime states should have control over their resources. Canada, at that time, knew nothing about the resources on her continental shelves. The time had come indeed. Canada was nudged again because the Americans wanted to know the field of gravity in the Canadian Arctic. If you are going to fly satellites you must know the pull of gravity, and if the satellites are going to be in a polar orbit, you really should know what the gravitational pull is in the polar regions. So, there were compelling reasons to start such an agency. In 1958 a Memorandum to Cabinet established PCSP, and we were officially on our way. In 1959 our first party went to Isachsen on Ellef Ringnes Island to find out how one undertakes science in the Arctic and to learn the problems that had to be overcome to support science in that environment.

---

[1] Polar Continental Shelf Project, Energy, Mines and Resources Canada, 344 Wellington Street, Ottawa, Ontario K1A 0E4

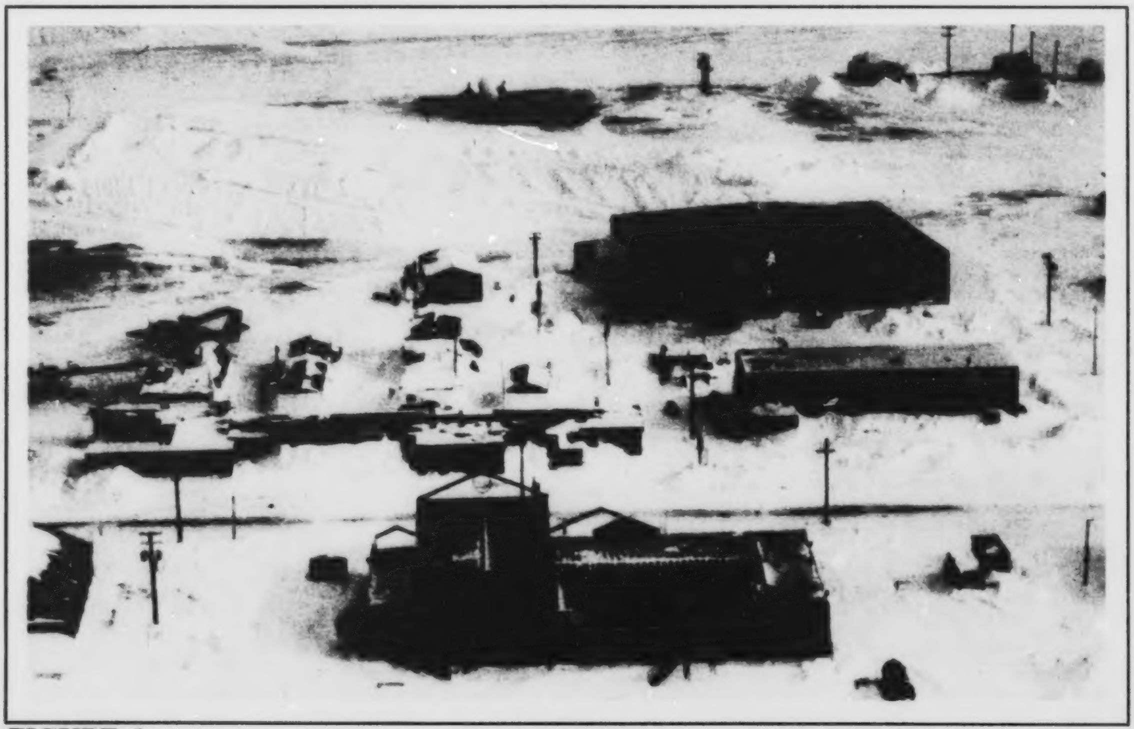


FIGURE 1: **Polar Continental Shelf Project base camp at Resolute - an aerial view in April 1989.**

Of course, Geological Survey of Canada parties had been active in the region previously, for example, during Operation Franklin in 1955 (Fortier *et al.* 1963), and

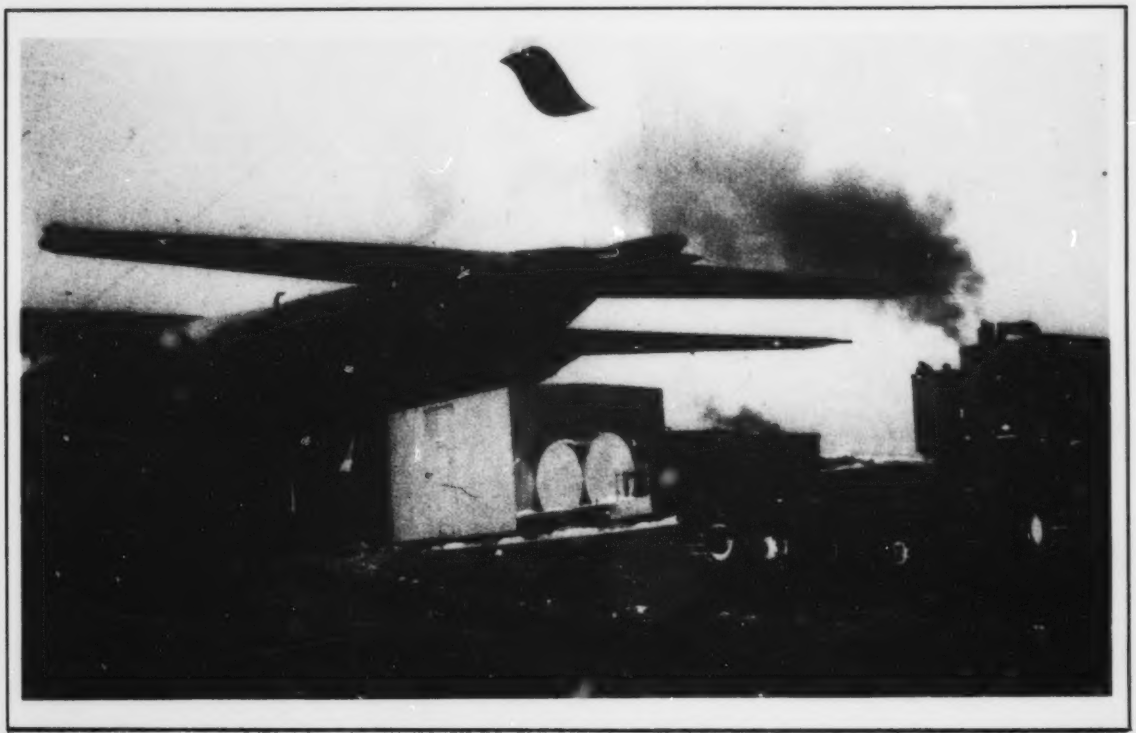


FIGURE 2: **Hercules transport aircraft at Drake Point, Melville Island unloading a bunkhouse and fuel tanks for a seismic survey across Sverdrup Basin. Such logistical support is a major part of PCSP's role.**

geologists such as Ray Thorsteinsson and Tim Tozer as early as 1947-1948 (Thorsteinsson and Tozer 1962; Tozer and Thorsteinsson 1964). But how does one do science on the fringe of the islands and on a much larger scale? There were eight people on that first party in 1959. Soon we were working from base-camps at Tuktoyaktuk and Resolute (Figures 1, 2), and by 1987 we had 235 parties asking for support. We estimate that there were probably 1,000 peaceful scientists in the Canadian Arctic in 1987 - and what better way to exercise sovereignty. In 1959 the budget was about $16,000; in 1987-1988 it was $5.1 million.

But we have had some highlights. In 1967 the former Dominion Observatory manned an expedition to the North Pole to study gravity and the deviation of the pendulum. In 1975 we undertook a joint operation with the United States in the Beaufort Sea, a period of 14 months in the project known as AIDJEX (Arctic Ice Dynamics Joint Experiment). In 1979 we had LOREX (Lomonosov Ridge Experiment; Weber 1989; Figure 3), in 1983 CESAR (Canadian Expedition to Study the Alpha Ridge; Jackson *et al.* 1985), followed by an ice-island project in 1983, when we boarded that "giant vessel" powerd by ocean currents.

FIGURE 3: Steve Blasco (R) and Brian Bornhold (L) analyze a marine sediment core during PCSP's LOREX (Lomonsov Ridge Experiment) project in 1979.

At one time PCSP had a staff of 26 scientists, most of whom were lost to the rest of the department in 1967-1968. The last three scientists were taken from Polar Shelf in April 1986. Now we are completely dedicated to the provision of logistic support to science.

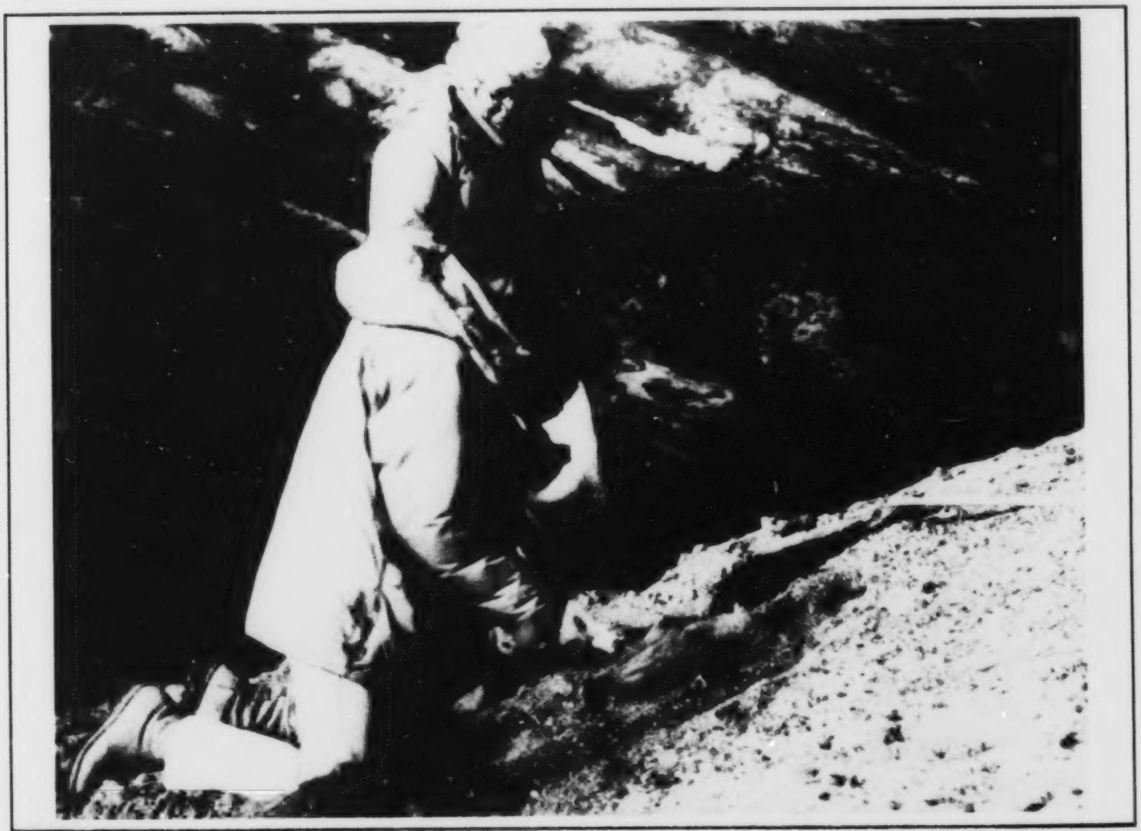


FIGURE 4: Mary Dawson (top) and Howard Hutchison (kneeling) collecting Tertiary vertebrate fossils in the Eureka Sound Formation near Bay Fiord, Ellesmere Island (see Dawson, this volume). The project was supported by PCSP.

We have had other highlights, such as participation in the discovery of a rhinoceros skeleton in the High Arctic (see Dawson, this volume; and Figure 4) and the discovery of the first dinosaur bone from the Canadian Arctic Islands (see Russell, this volume), all of which are exciting events. Indeed, this is perhaps where PCSP staff gets a lot of its satisfaction ... seeing scientists getting into the Arctic, doing their thing and doing it well.

At this point I would like to quote from Hansard of May 26, 1959:

> "The Arctic Archipelago, the Polar Ice Cap and Arctic waters are of vital economic and military significance. Large areas of sea ice may be used as airfields and semi-permanent bases for scientific or military

> purposes. Submarines are capable of surfacing through the Polar Ice Cap and in open leads without detection".
>
> "Development of similar latitudes in Russia shows a marked advance; so much so that the Canadian Government is placed in the position of obtaining most of its Arctic scientific knowledge from information supplied to us from time to time by the Russians."
>
> "A scientific group has now been sent to the Polar Continental Shelf to study hydrography, oceanography, geology and other geophysical characteristics of the shelf and adjacent land areas. The expedition this year is in the nature of a reconnaissance. Because of the vital nature of the work being undertaken it is essential that this group be expanded by at least four times next year with steady increases thereafter. The scientific work on the Arctic Ocean Continental Shelf should be a continuing effort until the mineral potential and major features of the area are known. In a rapidly shrinking world our sovereignty in the North must be continually reviewed and strengthened. There is no more effective way, no means less costly, and no method intrinsically more useful, of strengthening our sovereignty in the North than by the conduct of thorough scientific field research programs and the publication of their results. The Polar Continental Shelf Project is one of such programs."

Have things really changed? Even in 1959 scientists working in the Canadian Arctic were being encouraged to publish. Indeed, PCSP has produced eight volumes of abstracts covering many such projects and publications supported by it (Hobson and Voyce 1974, 1975, 1977, 1980, 1983, 1985, 1987, 1989). Those are a few of the highlights of PCSP history.

Let's discuss some of the Arctic science policy today. As we can see, Polar Shelf was originally concerned with sovereignty. It was one of John Diefenbaker's visions of the North. What better way to exhibit, gain, maintain sovereignty than to have 1,000 peaceful scientists walking around the countryside (Figures 5, 6)? Scientists can establish Canadian sovereignty. Let us recall Norway and Denmark who argued over Greenland: Denmark sent its scientists to Greenland while Norway ignored the opportunity ... and who has Greenland today? We scientists *are* Canadian sovereignty. Canada's investment in science may have been one of the cheapest yet most effective means of establishing a sovereign base for our northern lands and seas.

Science in the North is conducted to meet three major Government purposes. The first one is economic and regional development, whether it is looking at the natural resources, or whether it is Health and Welfare Canada participating in the regional development of the settlements. The second purpose is to support government missions,

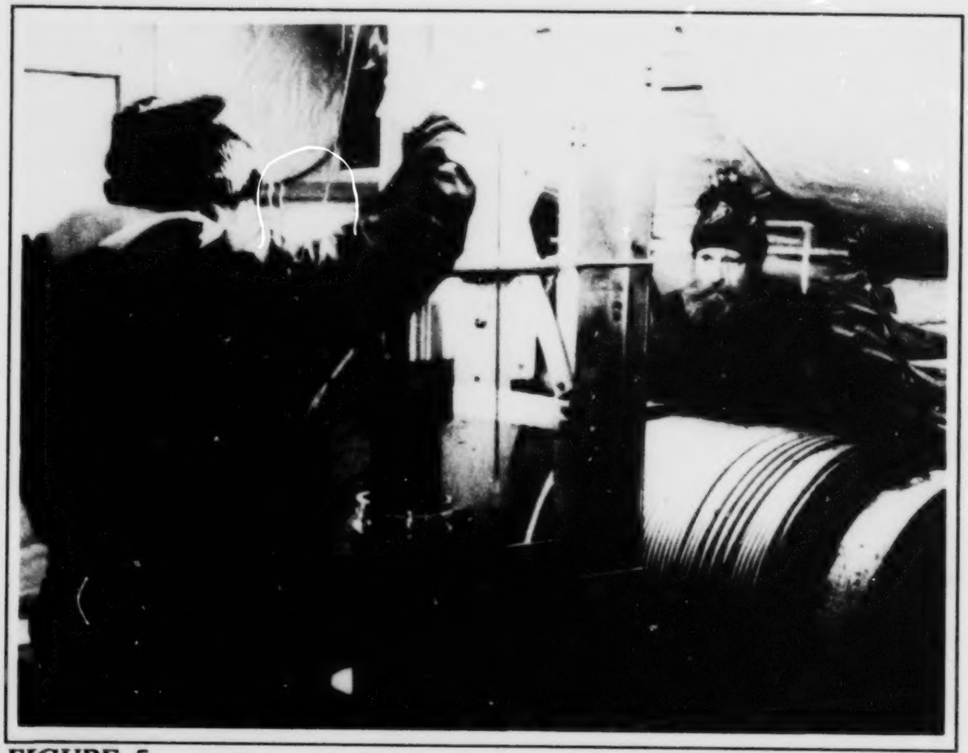


FIGURE 5: Fritz Koerner (L) and Lief Lundgaard inside a Parcoll hut taking an ice core from the Devon Island Ice Cap - a PCSP project.

FIGURE 6: Narwhal studies near Pond Inlet, Baffin Island, were also supported by PCSP.

whether it is national security, the safety and health of Canadians, the study of the environment, cultural development or just plain policy-making. The other, purpose for being in the North is to advance knowledge and the supply of highly-qualified people. But I have one criticism: the Federal Government, since the early 1970s, appears to have redirected much of its support for long-term, sustained research and systematic data-gathering to the resolution of urgent short-term policy and political problems associated with non-renewable resource development or surveillance for defence. Certainly, most scientists working in Canada's North would agree that there is a chronic shortage of funds to support polar research in Canada. There has also been a serious decline in the infrastructure that supports polar science.

Furthermore, polar science in Canada is not well coordinated - a fact brought out in the publication "Canada and Polar Science" (Adams *et al.* 1987). Each agency operating in the Arctic is autonomous. There are more than 20 government agencies, 34 or more universities in ACUNS (Association of Canadian Universities for Northern Studies), Provincial and Territorial government agencies, native development corporations, as well as individual and private organizations, in the North. All are trying to carry out this work. But who makes Northern science and research happen? Who identifies the need for Arctic research? The answer to these two questions is - *no one*. There is a need for pulling together all the pieces, and someone should identify the gaps in northern science. Perhaps the first recommendation in "Canada and Polar Science (Adams *et al.* 1987, p. 114) should be supported i.e. "... that a new, federally funded institution dedicated to understanding, funding or managing research in the Canadian North and the polar regions NOT be established at this time or in the near future". However, perhaps we do need an Arctic Research Commission - the second recommendation. There is a lack of cohesion, and no body other than the Federal Government in Canada has the capacity or the mandate to ensure that necessary research in the Arctic is undertaken.

The Colwell Report, recently released in the United States, urges that the National Science Foundation in the U.S.A. take the opportunity to integrate polar science into a broad, global, system-oriented program at the frontier and at the frontier of science. Another recommendation in the Colwell Report is that the funding for polar science be doubled. The Arctic Research Commission in the United States has reported to the

President, and there is a strong desire, at a high level, to increase the budget for science (U.S. Arctic Research Commission 1988A,B).

Let me go on to land-claims. I have been involved with some of the settlement claims, particularly those concerning COPE and Nunavut, and on the periphery of the Dené/Metis and Yukon settlements (Indian and Northern Affairs Canada 1985). Some of us have been impelled to face up to the rules and regulations of these settlements, and I think that we are all going to have to deal with those rules and regulations in the very near future. Nunavut is the largest claim in the country - land equal in area to the combined extent of Manitoba, Saskatchewan and Alberta. Also, consideration will be given to native peoples controlling the offshore area, which is in none of the other settlements. Therefore, we are looking at a massive area of Canada that may be controlled by native peoples. Some 16,000 native people will control a big part of our country, including much of the Sverdrup Basin - a good part of the land that you and I think they have never used for hunting or fishing. Some 17 sub-agreements have been signed, such as those pertaining to wildlife, access to the land, archaeology, national parks, etc. We are speaking about the balance between land-ownership and cash compensation in the arbitration process that is occurring. Both must be resolved. And they must be resolved with perhaps other considerations. The native peoples are going to get money as well as some 400,000 square miles (1,036,000 sq km) of land. It may be as much as 32,000 square miles (82,880 sq km) in the offshore. These numbers may not be exact, but at least they indicate that a lot of country is involved. And one of the things that the native people will want is *jobs*.

If you have been following the territorial situation, you will be aware that there is no party government in the Northwest Territories. A major problem facing that government is deciding how they are going to govern and be governed. Some people say that Nunavut means "our land". It is not the government's land. No treaty has ever been signed and aboriginal title and rights have never been relinquished. On the other hand, some would say that the North is government land. After all, government has been managing it for decades. We have two different opinions; that of the Inuit and that of the government. Can the land be owned by two different groups? That is why we have land-claim negotiations today.

In late September 1987, I attended the Alaskan Science Conference in Anchorage. It was interesting to sit in a workshop with a panel of three native people, and it was more interesting to hear what those native people had to say. I caution you that we should pay attention to what the native people are saying. At the individual and regional level, they must be involved in research. I can hear Arctic scientists now: "How can any native people plan my program?" But, native peoples must be involved in research. The local people want to decide what is going to be studied if it is going to affect them. For example, the people in Arctic Bay want to participate in a geological program, especially if it is going to result in discovery of another mine. They want to take part in our research design. They want to set the agenda. These are the words that have been used. They want to be involved from the start to the end. They should be consulted even in data-interpretation and surveys. Do I speak for Arctic scientists when I say that maybe we are just a little bit egotistical, and wonder how they can participate in the interpretation of our data? That's what they want, and that is it what you and I must be prepared to face. But behind that, they want to encourage their young people to get into science, they want to develop managers, to become involved. Past procedures must change. Native people are concerned that a lot of the research does not address local problems. They are not happy with the way we have gone into their backyards, carried out field work and returned south with our rock samples, with our artifacts, etc. They want a stake in their land and a say in how it is handled.

Another thing the native people want us, as scientists, to remember is that their cultural and religious backgrounds are different from ours. It is particularly important to recognize this when we undertake wildlife investigations. There is a spirit that you and I are seldom aware of; few of us have ever been involved in that part of their lives. Do we appreciate sufficiently their religious and social background? I would have to say "No". They want us to be sensitive. Sometimes a native will say "No" to us without explicitly using the word "No". They will intimate to us that they don't want something, and we don't listen to them because we have neither the social background, nor perhaps the sensitivity to clearly understand them.

Another prime consideration is that information gathered by scientists must get back to the settlements. How many of us have sent a map back to the settlements? How many have sent a publication dealing with their backyard? I think I may have hit a few nerves here! Once I took a cardboard box of every publication we have in our library pertaining to the Tuktoyaktuk Peninsula to a Council meeting in Tuktoyaktuk. Although I don't know what they did with the information, at least they have it. How many of you have taken publications back to settlements in the vicinity of your field areas. I emphasize that native people not only want to know what is going on in their backyard, they have a right to know (Figure 7). These people are puzzled why they can no longer go into their backyards, or their flower garden, because it has been made into a national park. Why can they no longer hunt in certain areas? There is the perennial complaint that people in the North tend to be treated as objects of study, but never hear the study results. Soon, I believe that we will see the research priorities established by native boards who will not only make decisions about natural-resource management, but who will control the resources to develop native researchers and conduct studies on their own.

FIGURE 7: George Hobson (L) of PCSP. The role of scientific liaison with people in arctic settlements is important. Pangnirtung, Baffin Island, July 1988.

We must remember that people are a part of the ecosystem. We have to involve people in our studies and in the collection and analysis of our data. These people want to be involved and you and I, in the new era, will have to consider their needs. When the last claim is settled, they will own the lands in principle, the same as you own the land on which your house is built. For too long we have undertaken our research in their backyards without consulting them. Soon, we will be obliged to recognize that they own the land and want to participate in advancing scientific knowledge in the Canadian Arctic.

REFERENCES

Adams, W.P., P.F. Brunet, M.R. Gordon, and E.F. Roots. 1987. Canada and polar science. Indian Affairs and Northern Development Canada, Circumpolar and Scientific Affairs Directorate, Ottawa. 116 pp. and appendices.

Fortier, Y.O., R.G. Blackadar, B.F. Glenister, H.R. Greiner, D.J. McLaren, N.J. McMillan, A.W. Norris, E.F. Roots, J.G. Souther, R. Thorsteinsson, and E.T. Tozer. 1963. Geology of the north-central part of the Arctic Archipelago, Northwest Territories (Operation Franklin). Geological Survey of Canada, Memoir 320.

Hobson, G.D. and J. Voyce. (Editors). 1974. Titles and abstracts of scientific papers supported by Polar Continental Shelf Project, No. 1. PCSP, Ottawa. 76 pp.

______. 1975. Titles and abstracts of scientific papers supported by Polar Continental Shelf Project, No. 2, PCSP, Ottawa. 68 pp.

______. 1977. Titles and abstracts of scientific papers supported by Polar Continental Shelf Project, No. 3, PCSP, Ottawa. 97 pp.

______. 1980. Titles and abstracts of scientific papers supported by Polar Continental Shelf Project, No. 4, PCSP, Ottawa. 89 pp.

______. 1983. Titles and abstracts of scientific papers supported by Polar Continental Shelf Project, No. 5, PCSP, Ottawa. 92 pp.

______. 1985. Titles and abstracts of scientific papers supported by Polar Continental Shelf Project, No. 6, PCSP, Ottawa. 79 pp.

______. 1987. Titles and abstracts of scientific papers supported by Polar Continental Shelf Project, No. 7, PCSP, Ottawa. 100 pp.

______. 1989. Titles and abstracts of scientific papers supported by Polar Continental Shelf Project, PCSP, Ottawa. 185 pp.

Indian and Northern Affairs Canada. 1985. The Western Arctic claim - the Inivialuit final agreement, DIAND, Ottawa.

Jackson, H.R., P.J. Mudie, and S.M. Blasco. (Editors). 1985. Initial geological report on CESAR. Geological Survey of Canada, Paper 84-22:1-177.

Thorsteinsson, R. and E.T. Tozer. 1962. Banks, Victoria and Stefansson islands, District of Franklin, Northwest Territories. Geological Survey of Canada, Memoir 330.

Tozer, E.T. and R. Thorsteinsson. 1964. Western Queen Elizabeth Islands, Arctic Archipelago. Geological Survey of Canada, Memoir 332.

U.S. Arctic Research Commission. 1988A. Entering the age of the Arctic, opportunities and obligations of an Arctic nation. (Report).

______. 1988B. Logistic support of Arctic research. (Report).

Weber, J.R. (Editor). 1989. Selected LOREX contributions. Geological Survey of Canada, Open File 2009:1-300.

Sod house + Inukshuk
Aug 5 1983

Illustrated by Brenda Carter

CONFLICT IN NORTHERN ACTIVITIES

R.L. Christie[1]

Abstract: Conflict is inherent in competition between countries, organizations, and individuals, and the stress due to competition and conflicting goals has played a large part in the development of the Arctic. Early voyages of discovery were motivated by aggressive national pride and competition for commercial sea routes; sovereignty and strategic concerns among Canadians are attributable to conflict, or the possibility of conflict, between nations. Conflicting goals in modern development of the North have led to widespread disadvantage for native northerners. The conflict between the requirement of massive funding for mineral or petroleum exploitation in the Arctic, and the lengthy passage of time and the doubts in realizing returns, has been a continuing burden. Conflicting goals of adventure versus 'good' research in northern scientific studies, evident in the Canadian Arctic Expedition, 1913-1918, may still be with us. Conflict in goals is useful to the extent that people's wits are sharpened and there is improved awareness of interests and problems.

Résumé: Les conflits font partie de la concurrence entre les pays, les organisations et les individus. Cette concurrence et des objectifs incompatibles ont fait surgir des tensions qui ont joué un rôle important dans le développement de l'Arctique. Les premiers voyages d'exploration ont vu le jour grâce à une grande fierté nationale et à la compétition pour des routes maritimes commerciales; les préoccupations de souveraineté et de stratégie chez les Canadiens viennent des conflits ou des possibilités de leur émergence entre les nations. Dans l'actuel développement du Nord, des objectifs contradictoires ont entraîné, pour les autochtones du nord, de vastes désavantages. Les conflits entre les besoins d'énormes capitaux pour l'exploitation des minéraux et de pétrole dans l'Arctique, les longs délais et les possibilités douteuses d'arriver à des résultats positifs sont un problème continu. Les objectifs contradictoires entre les recherches scientifiques dites "hasardeuses" et celles qualifiées de "bonnes", qui sont apparus lors de l'expédition dans l'Arctique canadien de 1913-1918, peuvent être encore présents. Les conflits d'objectifs sont profitables dans la mesure où il faut travailler les esprits et améliorent la conscience des intérêts et des problèmes.

INTRODUCTION

A philosophical geologist, M.T. Greene (1982), remarked: ... "communion with nature is a prelude to battle with naturalists". This, and other observations, led me to the subject of this paper: that conflict has been and is inherent in our way of doing things. Conflict, in broadest terms, is part of the way humans operate; it toughens and often brings out the best in us. However, we are in fact trained to avoid conflict. Extremes in conflict are so obviously destructive - even life-destroying - that the reaction of our protective parents (notice that they are called 'guardians') is to attempt to turn us toward beautiful, soul-satisfying 'cooperation', 'love', 'friendliness' ... the lamb lying down with the lion, and so on. I do not discuss here nasty conflict, or armed conflict. For conflict read also competition, or stress. The motivation may be self-preservation, but the conflict I am concerned with is not at the level where the adrenalin is flowing.

---

[1] Polar Continental Shelf Project, Energy, Mines and Resources Canada, 344 Wellington Street, Ottawa, Ontario K1A 0E4

Anti-conflict moves can be productive, of course (e.g. a conciliation board, an ecumenical council, or cooperative projects). But the prime mover in each of these cases is conflict, or the threat or possibility of it.

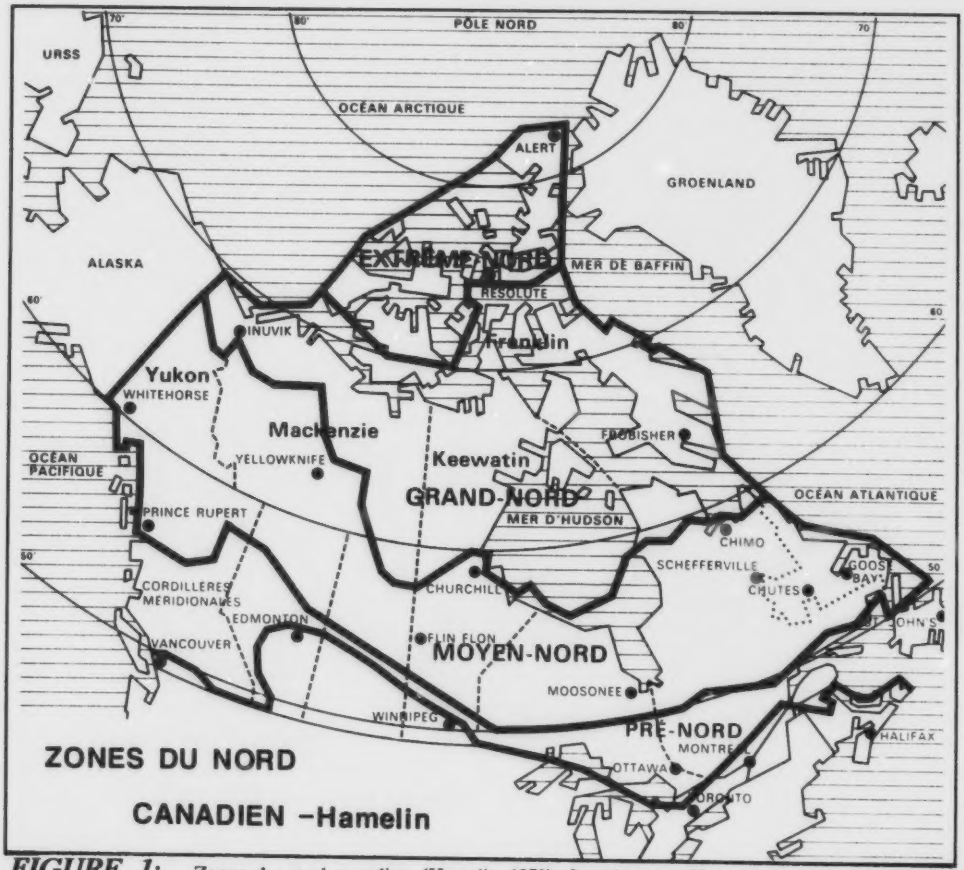

PÔLE NORD
URSS
OCÉAN ARCTIQUE
ALERT
GROENLAND
ALASKA
EXTRÊME-NORD
MER DE BAFFIN
RESOLUTE
INUVIK
Franklin
Yukon
WHITEHORSE
Mackenzie
FROBISHER
OCÉAN PACIFIQUE
YELLOWKNIFE
Keewatin
GRAND-NORD
OCÉAN ATLANTIQUE
PRINCE RUPERT
MER D'HUDSON
CHIMO
SCHEFFERVILLE
GOOS BAY
CHUTES
CORDILLERES MERIDIONALES
CHURCHILL
EDMONTON
OHN'S
FLIN FLON
VANCOUVER
MOYEN-NORD
MOOSONEE
WINNIPEG
PRÉ-NORD
HALIFAX
MONTRE
OTTAWA
ORONTO
ZONES DU NORD
CANADIEN -Hamelin
70
80
60
50

FIGURE 1: Zones du nord canadien (Hamelin 1970). In this map, Hamelin expresses degrees of 'nordicity', which incorporate various factors such as summer and annual temperatures, plant-cover, and accessibility from 'the South'.

The very idea of Man in the Arctic is an exercise in conflict, at least at first glance, and from our mainly southern perspective. Inherent in the expression: 'hostile environment' - so often heard of the North - is the concept of conflict. A view of Canada from the south is evident in Hamelin's (1970; Figure 1) illustrations showing 'nordicity'.

An American architect, in a recent Public Broadcasting System documentary, remarked that "... every house is, for its occupant, a private sanctuary and a public stage". You see in that the potential for conflicting goals: the house must satisfy at least two opposing needs, and a glance at a house often says something about the characters within. So, what do outside viewers think of people who are of the North when they look at our house? How are the conflicts that are inherent in northern human activity balanced? If all is calm, and the lamb is nestled with the lion, then perhaps something is wrong; something is hidden. Either the lamb or the lion is putting on an act!

Let's look at five areas of activity in the North to see what conflict there has been, and where conflict occurs today. In doing so, we may discover the state of health of northern activities, or see what use the conflict can be. Undoubtedly, a deeper investigation than I am concerned with here would uncover a great deal more conflict. But this is a personal account, and I hope to create a positive view of the North.

HISTORICAL CONFLICT

The Canadian North is defined in political terms: from the outside in, rather than as native northerners would describe it (it was, to them, The World). The Canadian North is the product of periods of competition. First, the English and Dutch commercial adventurers (from 1553) sought alternatives to southern sea-routes around Africa and around South America, which were discovered and controlled by the then dominant maritime powers, Spain and Portugal. Following the Napoleonic wars (ending 1815), Britain supported geographic exploration in competition with Russia. The British-Canadian North was bounded on the west (as Canada is now) by Alaska (Figure 2), a huge land that was the subject of areal and boundary discussions and disputes between 1821 and 1825.

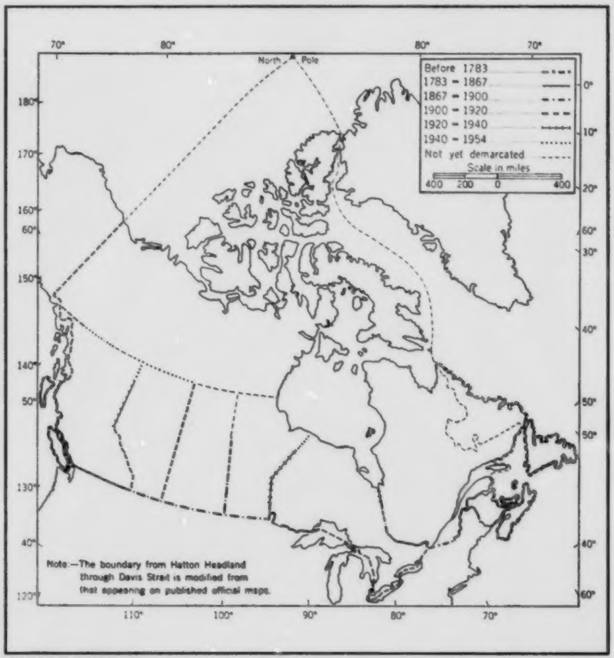

North Pole
Before 1783
1783 – 1867
1867 – 1900
1900 – 1920
1920 – 1940
1940 – 1954
Not yet demarcated
Scale in miles
400 200 0 400
70° 80° 80° 70°
180° 170° 160° 60° 150° 140° 50° 130° 40° 120°
0° 10° 20° 60° 30° 40° 50° 50° 40° 60°
110° 100° 90° 80° 70°
Note:—The boundary from Hatton Headland through Davis Strait is modified from that appearing on published official maps.

FIGURE 2: **Map showing the stages of delineation of boundaries of and in Canada (Nicholson 1954, p. 98).**

(The disputes were finally settled between the United States and Canada in 1903, the Americans having purchased Alaska from Russia in 1867) (Nicholson 1954; Sollie 1983).

Sometimes places in the Canadian North can be identified from reading historical accounts, or even from the character of current geographic names, with various European countries. The Sverdrup Islands and southern and western Ellesmere Island - Norwegian "New Land" - immediately come to mind. Americans left their mark in northern Ellesmere Island and some southern whaling areas, and in fabulous "Crocker Land". The point is that national loyalties and international competition played their parts in the opening of the North. Never did this amount to warlike behaviour - Robert Peary refusing to stop for coffee with Otto Sverdrup (1904, Volume I, pp. 57-61) is all I can remember! The effect of such competition was wholesome: these men were striving to achieve more than personal goals.

Much of the archipelago was explored by British sailors in a massive search for their missing countrymen - Sir John Franklin and his crew. This achievement, also, to a great extent, was a consequence of national pride.

CONFLICTS IN NORTHERN POLITICS

Many conflicts present themselves: Canadian sensibilities over sovereignty vs international maritime rules; the strategic, international importance of the North vs our southern preoccupation with economic and military problems in areas where most of the people live; conflict between those who care about wildlife, or depend upon wildlife, and others who may have national or private commercial interests (e.g. Greenpeace vs the whale hunters); the conflict between northern pragmatists, the people who live, work, earn a living in the North, and the academics and idealists in the South. I could go on: books appear regularly on these topics.

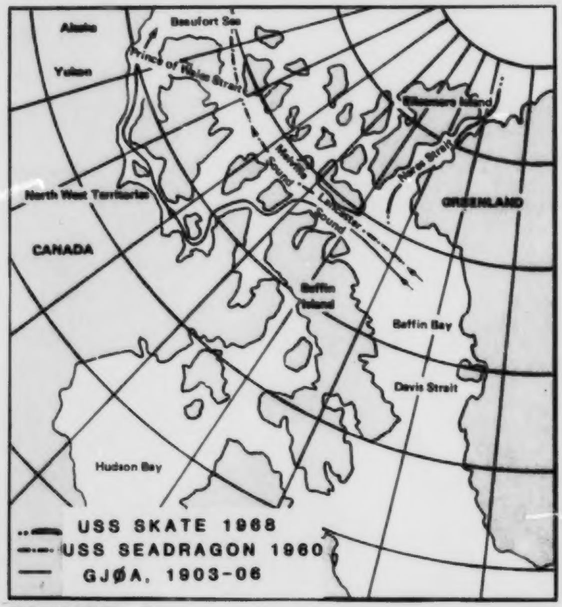

Alaska
Yukon
Beaufort Sea
Prince of Wales Strait
Ellesmere Island
Melville Sound
Nares Strait
North West Territories
GREENLAND
Lancaster Sound
CANADA
Baffin Island
Baffin Bay
Davis Strait
Hudson Bay
USS SKATE 1968
USS SEADRAGON 1960
GJØA, 1903-06

FIGURE 3: Map showing some ship and submarine traverses of the North-West Passage, as well as the more northerly route of U.S.S. Skate. (Bach and Taaghold 1982, p. 43).

Although some British sailors walked part of and sailed the rest of the North-West Passage in the 1850s, it was a Norwegian, Roald Amundsen (1909), who first navigated it in the *Gjøa* in 1903-1906 (Figure 3). That was well after the Far North had been given over, at least in a major part, by Britain to Canada. The *St. Roch*, commanded by Henry Larsen of the Royal Canadian Mounted Police, sailed through the Passage in both directions in the 1940s (Larsen 1958). Whatever the history and the legal arguments, Canadians have taken the Passage, and indeed, all the magnificent channels of the archipelago as their own: they have been traversed by trading ships and government maritime patrols for decades. Also, it may be important in future judgements that the channels have been travelled as a matter of course by land-based people such as hunters and scientists, the frozen channels essentially becoming, albeit seasonally, one with the land (see, for example, Miller, this volume).

At present, this conflict has yet to be resolved. There exists between Canada and the United States an uneasy tension: continental cooperation achieved in many areas on the one hand, but unresolved disputes, including the question of ship-transit through the archipelago, on the other (Vanderzwang and Lamson 1986).

STRATEGIC IMPORTANCE OF THE NORTH VS OUR COLLECTIVE PREOCCUPATION WITH SOUTHERN AFFAIRS

First, consider that military conflict, or its potential, has led to important advances in the Far North: the building of a travel and communication network of airports, weather stations, radio and radar systems, and, through advanced technology, the ability to travel and work at almost any time and anywhere in the North.

Military conflict of the Second World War led to the construction of the Alaska Highway and the Canol Pipeline and Road. Postwar fear of conflict resulted in the building of the Joint Arctic Weather Stations (JAWS), Thule Air Base in northwestern Greenland, and Distant Early Warning (DEW) Line stations.

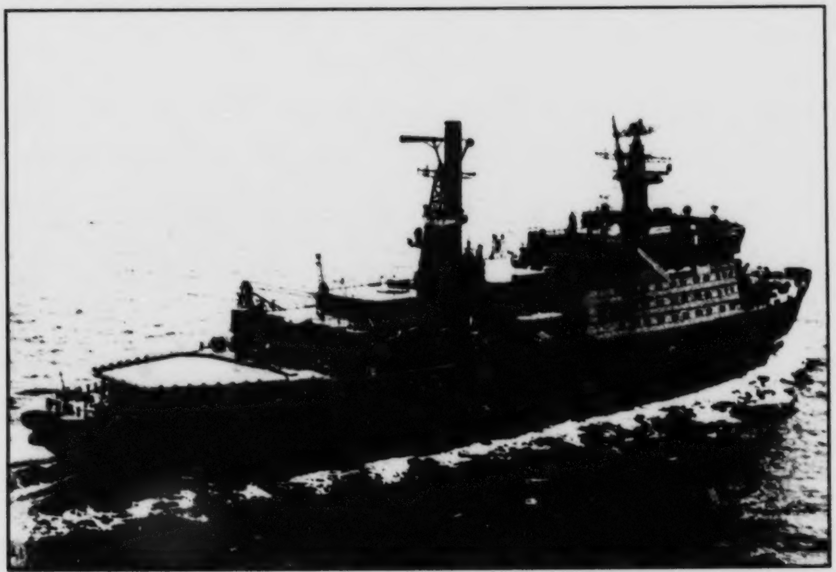


FIGURE 4: The Soviet nuclear-powered icebreaker Arktika (later Brezhnev) reached the North Pole in 1977.

Advances in marine science and the potential for military conflict have led to great progress in northern hydrography, sea-bottom studies, marine geology, and oceanography. The High Arctic, once safe to ignore as more or less inaccessible, is now part of the modern world. The Soviet icebreaker *Arktika* (later *Brezhnev*) (Figure 4) reached the North Pole in 1977, as did the *Sibir* in May 1987.

Station Nord, in northern Greenland, was supplied by the icebreaker *Ymer* in 1980. Nuclear-powered submarines have been travelling our Arctic channels who knows how long or how often? The American submarine *Skate* crossed the North Pole in 1968. The recent location and exploration of the *Titanic* is but another step in man's increasing ability to travel and work in strange and forbidding parts of the globe.

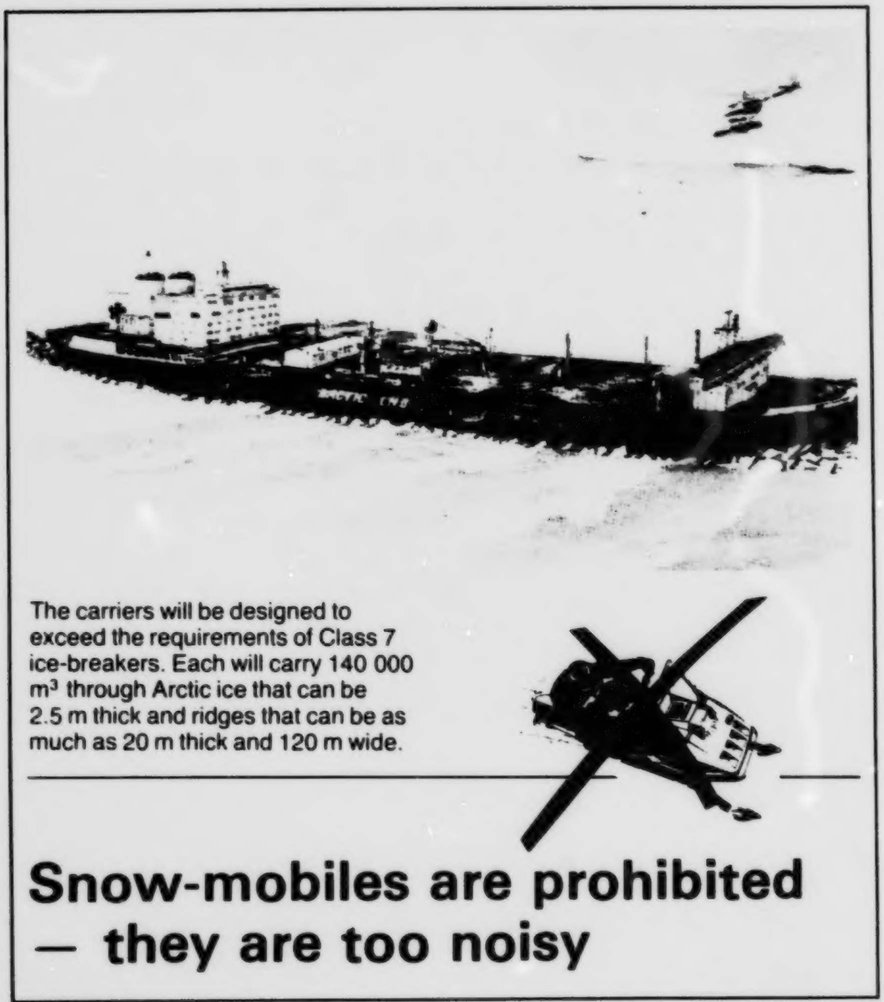
These developments and activities are 'advances' from a southern perspective but may be of dubious value to some northerners, who see their way of life threatened or destroyed, and their basic sovereignty and dignity placed in doubt. Danish writers on strategy, Bach and Taagholt (1977, 1982), conclude that to ensure sovereign rights in Greenland (in light of the need for defence cooperation with the U.S.A. and North Atlantic Treaty Organization), Greenland/Denmark must cooperate and keep all sea and air-routes open for all nations; in other words, avoid conflict.

Wildlife

The conflict between Canadian and world sensibilities about clubbing newborn seals and the commercial gain from the activity is now part of history, and as we know native seal hunters throughout the North have been inadvertent victims through the depression of prices for all seal pelts.

A contemporary battle between the Greenpeace organization and the whaling industries of certain nations, especially the U.S.S.R., Japan, and until recently Norway, is still being fought. This battle is on a global scale, with widely - scattered skirmishes (e.g. whalers, described as 'bandits', were filmed in northeastern Asia, and a whale-conservationist protest took place in Brighton in 1983 (Anonymous 1983)). An advantage of the continuing conflict between the conservationists and the whale-exploiters is that the former are reliable, if not always likable watchdogs. They provide interesting facts about the activities of large-scale hunters such as those of the national whaling industries.

Close to home is the conflict between the proposed Arctic Pilot Project (APP), and the Inuit of Canada and Greenland. The APP would be an invasion by large ships to exploit northern hydrocarbon resources. On one hand, private operators hope to make a profit, and on the other, hunters wish to have their resource undisturbed (and unsoiled). The Inuit declare that the tankers are too noisy: not even the clatter of snowmobiles is allowed in Greenland (Anonymous 1980, 1982; Figure 5)!



The carriers will be designed to exceed the requirements of Class 7 ice-breakers. Each will carry 140 000 m^3 through Arctic ice that can be 2.5 m thick and ridges that can be as much as 20 m thick and 120 m wide.

Snow-mobiles are prohibited — they are too noisy

FIGURE 5: An artist's drawing in Greenland Newsletter of a LNG (liquid natural gas) carrier, with a protestation against engine noise (Anonymous 1982).

Pragmatists vs Idealists

The northern pragmatists are the local people, including hunters, prospectors and transportation workers. They wish to live, to survive, and their goals are immediate financial and physical well-being, as well as local autonomy. Outsiders tend to want to control some of their activities: world concern for polar bears, for example, resulted in imposition of local quotas on these animals in our northern settlements (Davids 1982, p. 120). A little farther south, those who harvest game for meat, or fish, tend to want to eliminate supposed competing predators such as wolves or seals. Other people, acting as watchdogs, take the side of the predator, so we have a hearty conflict, again.

Native people like to bring down fat geese by shooting them on the wing; lawmakers on occasion insist that the natives obey southern hunting restrictions. This is a conflict between advancing population and development from the south and values that native northern peoples consider are essential to their culture.

CONFLICT IN THE SOCIAL DOMAIN

Invasions from the South

The Arctic, from a southern perspective, is a frontier; an alternative view is that of a homeland. Socially, southern movement into northern areas is an 'intrusion'. The economic goals of southern industry are in conflict with both the earlier and later social styles of the region, and are often even in conflict with social goals of the southern, or central government. The effects that the dominant, industrialized societies have had on the economic and social development of the northern peoples have been dramatic, and the conditions in the North have much in common with those of 'third world' countries (Griffiths 1983). The histories of the North, however, have differed from place to place. Griffiths graded northern native groups according to perceived degree of self-determination and, presumably, ability to carry on in their own life-style as follows: (1) Soviet Arctic peoples; (2) Sami (northern Scandinavia); (3) Greenlanders and Alaskan Inuit; and (4) Canadian Inuit.

The present condition of the Canadian Inuit was regarded (Griffiths 1983) as 'colonial', or of the lowest status.

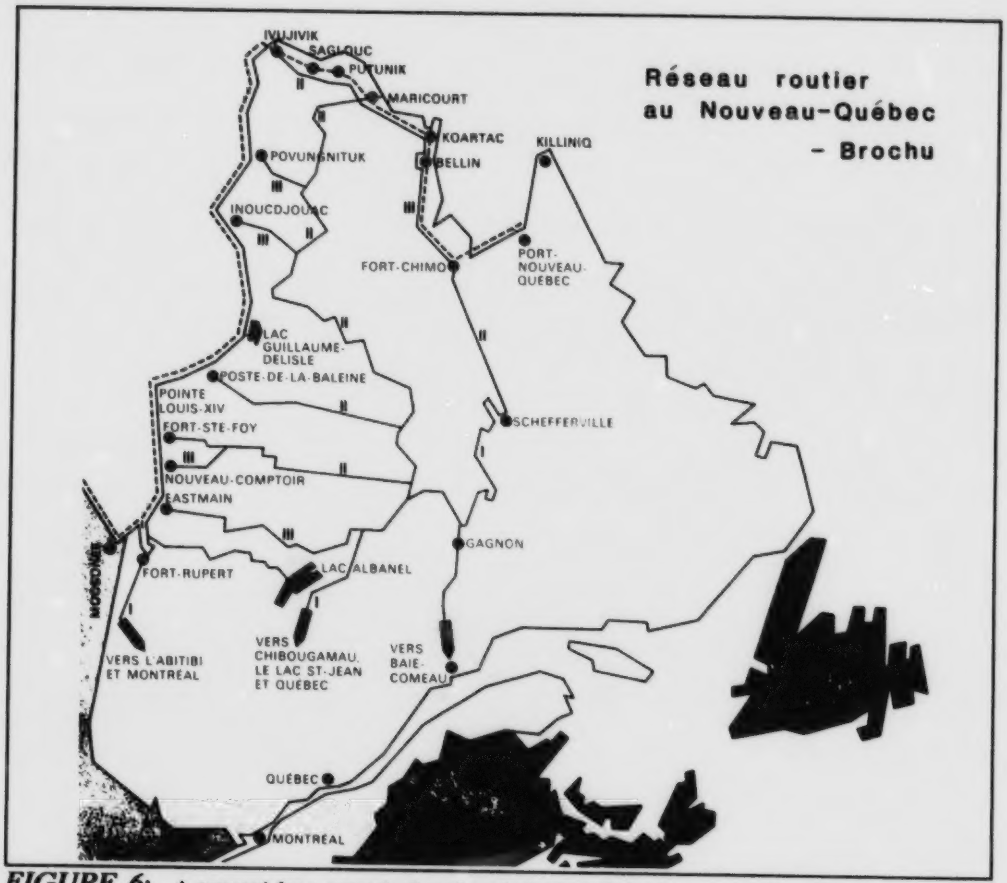

Réseau routier
au Nouveau-Québec
- Brochu
IVUJIVIK
SAGLOUC
PUTUNIK
MARICOURT
KOARTAC
BELLIN
KILLINIQ
POVUNGNITUK
INOUCDJOUAC
FORT-CHIMO
PORT-NOUVEAU-QUEBEC
LAC GUILLAUME-DELISLE
POSTE-DE-LA-BALEINE
POINTE LOUIS-XIV
FORT-STE-FOY
NOUVEAU-COMPTOIR
EASTMAIN
SCHEFFERVILLE
GAGNON
FORT-RUPERT
LAC ALBANEL
MOOSONEE
VERS L'ABITIBI ET MONTREAL
VERS CHIBOUGAMAU, LE LAC ST-JEAN ET QUEBEC
VERS BAIE-COMEAU
QUÉBEC
MONTREAL

FIGURE 6: A proposal for a network of roads and winter-roads for Nouveau-Québec (Brochu 1970, p. 29).

Southerners going to the North, since the times of the earliest invasions, have had problems in adapting. They created their own problems to a great extent, and Vilhjalmur Stefansson throughout his career elaborated on this. Today, as ever, southern technocrats see problems in the isolation of industrial complexes in the Arctic, and workers often spend a number of weeks 'in' and almost equal time 'out', with the attendant problems, danger, and high cost of travel. The alternatives of integration with existing communities, or of training northerners, with their different work ethics and social values, are continually being considered. So far, little has been achieved.

The view of the North as a frontier, complete with an 'invasion' philosophy, can be seen in a proposal (Brochu 1970) for a network of roads for Nouveau-Quebec (Figure 6): this Réseau-routier has all the character of the tracks of a Panzer division.

Consider housing. The traditional Inuit house, or *iglu*, was open-plan, with an extended family or more than one family, living in it. Our intrusive society encourages one family per house, and the house is divided into rooms. The aboriginals did not claim ownership of land, or of unoccupied houses; the intrusive society, however, requires ownership and an investment of money. The resulting commitment is in conflict with the independent, nomadic urges of a basically hunting and travelling people.

Social conflict in different parts of the North has varied enormously. The contrasts in the social histories of Greenland, Arctic Canada, and Alaska (Sugden 1982), are reviewed below.

Greenland

Greenland was kept 'closed' by Denmark between 1721, when Hans Egede arrived, and 1948, when the Greenland Commission of that time recommended change from a colonial status. The Greenlanders, during this long period, were shielded from world trade; a hunting life was maintained, with gradual movement toward a more commercial style through selling part of their catch. Then, during the Second World War, in which Greenland fell under the protection of the U.S.A., new outlooks arose.

After 1953, two elected members of the Danish parliament were sent from Greenland. Transportation, schools, and health-care were promulgated and by the late 1950s Greenland's population was increasing annually at 4%. A Greenland Committee of 1960 declared a policy of wholesale investment, concentration of population in existing, larger urban settlements, and development of the all-season marine fisheries as a mainstay of trade. Four open-water fishing towns grew explosively, and investment in boats, processing plants, technical schools, and utilities soared. Danish language was emphasized in schools, which were re-oriented toward an industrial society, and skilled workers poured in from Denmark.

However, by the 1970s there were in effect two Greenlands: large towns with many opportunities and high standards of living on one hand, and shrunken or abandoned, peripheral villages with subsistence living and rudimentary services on the other. Sons and daughters migrated to the large centres. Social demoralization grew; the emphasis on Danish and the presence of so many highly-paid Danes led to alienation. Drunkenness, violence, suicide, and political protest arose.

A key factor in the developing dissatisfaction was a decline in the cod catch in the mid-1970s, despite an improved fishing fleet. With the main economic base weakened, Danish policy shifted back to a more country-oriented style and the number of resident Danes was reduced. Greenlandic teachers were encouraged, and home rule was achieved in 1979.

The crux of the problems in Greenland was the conflict between industrial, economic, and social goals of government and people. The social problems outran the attempt to achieve self-sustaining economic growth.

The Canadian Arctic

Canada's Arctic, in marked contrast with Greenland, has been dominated by laissez-faire, and has been open to world exploitation of resources. The original, self-sufficient Inuit communities were extensively invaded by American and British whalers in the 1860s, with devastating impact. The Inuit gathered at ship wintering-sites, game was cleared, and when the whaling industry collapsed (by 1907), Inuit populations were decimated by starvation and epidemics. A second economic boom, that of fur-trading with the Hudson's Bay Company, grew after 1910 and lasted until the late 1930s. This industry again concentrated the population in small centres, this time consisting usually of a trading post and a Royal Canadian Mounted Police detachment at least, and introduced a cash economy and many southern goods. During and after the Second World War, with the development of air bases (e.g. Frobisher Bay), weather stations (JAWS), and the DEW Line, a communications and air-route infrastructure grew.

The rapid construction, largely financed and carried out by United States-dominated operators, inspired a wave of social concern among Canadians; and hospitals, medical programs, and schools appeared. A widespread housing program was begun, Inuvik was created as the hub of the Mackenzie Delta region, and Inuit cooperatives were encouraged.

A fourth wave of activity followed the discovery of the Alaskan Prudhoe Bay oil field in 1968. Between 1970 and 1975, some $500 million was spent on oil exploration in the Beaufort-Mackenzie area and the Canadian Arctic Islands. Lead-zinc, copper, asbestos, tungsten, and nickel mines opened.

The development of the Canadian Arctic has been a typical colonial enterprise: long north-south transportation links to the peripheral resource area, with the resources often going directly overseas and investment commonly being foreign or multinational. The conflict lay between short-term development by outsiders and the social goals and well-being of residents. The economic benefit of this exploitation has been of short duration and in some cases of doubtful value.

Canadian Inuit were largely ignored in several of the developmental rushes, and to a great extent lost their distinctive way of life. The centralizing effect of stores, missions, schools, and administrators resulted in local overhunting and increased dependence on welfare. Children were educated in a non-native culture, yet were unable to compete with the intruding people for jobs. Loss of traditional values and prestige resulted in a downward, demoralizing spiral.

However, in Canada, as in Greenland, native and other sentiments were aroused, and more local autonomy and land ownership or rights were demanded in the 1970s; now they are being achieved. A new style of development may be arising in Canada: some mining and petroleum operations are treated as temporary projects connected to the South and are separated from the northern, permanent infrastructure, which focuses more on the Inuit. This is in contrast with the Greenland style, in which postwar economic and social policies and developments are integrated.

Alaska

In Aleut, Alaska means 'the great land' - it is an apt description. Before the historical invasions from the outside, Alaska was home for some 62,000 native people, including Aleuts, Inuit, Athapascans, and other tribes in the southeast. They lived in small villages. Alaska underwent five main intrusive waves between the early 1700s and the present.

From the 1740s, Russians quested for fur seals and sea otters in the Aleutian Islands, with peak activity between 1770 and 1867. The Aleut population decreased from 16,000 to 2,000 by 1840, and the village social structure was destroyed. This decimation was accomplished through forced migration, enslavement, and disease.

Whalers arrived in 1847, and in the course of this exploitation Inuit villages of the west and north coasts were devastated by disease. Whales - the basis of livelihood for the aboriginals - were much reduced in numbers, and the late 1800s saw wholesale starvation among the Inuit.

In 1869, gold was discovered at Nome, but the deposits were rapidly exhausted. Gold was found at Fairbanks in 1906, however, and became an economic mainstay until the Second World War. The native population of Alaska stabilized at about 30,000 following the decline that had taken place throughout the 1800s.

A fourth invasion, during the Second World War, was a friendly one by some 152,000 troops. Concerns over possible (and, in fact, an actual) Japanese invasion, and later about Soviet intentions, resulted in: (1) the rebuilding of the Anchorage-Fairbanks railway (built during an earlier boom); (2) construction of the Glenn and Alaska highways; and (3) the building of airfields and DEW Line stations. By 1952, 52% of the labour force in Alaska was on the military payroll.

An oil boom followed the discovery at Prudhoe Bay, on the North Slope. Oil had been found in 1957 on Kenai Peninsula, where production commenced in 1960. However, the Prudhoe Bay field was a quantum leap in petroleum terms.

Alaska, (like Canada's Arctic), has basically a colonial pattern, with coastal cities and inland centres peripheral to the large southern gateway, Seattle. A major difference, however, was the scale of the economic waves. Vast numbers of 'mainlanders' invaded the Alaskan territory (in 1959, a state), settling in a relatively agreeable land, and lending dynamism to the region. The American frontier ethic created an environment of unfettered capitalism. Economic exploitation was more than an opportunity to be grasped; it was a duty! However, economic goals eclipsed social goals: the immigrant population prospered at the expense of the native people.

The late 1970s witnessed a remarkable development. Life for Alaskan Inuit shot from a struggling existence to a position of strength. Oil property-taxes and royalties were spent locally to achieve native Alaskan social and economic goals. The 1971 Alaska Native Land

Claims Settlement Act, in effect, created a form of statehood for native Alaskans (cf. Hobson, this volume). The act was the culmination of several forces, including the recognition of the widespread disadvantage of native people, and the economic and strategic need of the United States to develop North Slope oil with minimal delay.

CONFLICT IN ECONOMICS

The basic conflict in the North is the same as elsewhere: the rush to make money vs quality in development and use of the region. This is another side of the conflict between the frontier and the homeland.

A potential example is the proposed park on northern Ellesmere Island. Substantial income is possible for certain northern operators, at thousands of dollars per tourist (and there were about 70 in the summer of 1987, though the park was not yet formally established). But how many visitors can the land stand before it is over-used and degraded, or the very solitude that is so valued by the visitor disappears? This problem, faced many times in more populated areas, has already been considered by people of Canada's territories (e.g. Butters 1973).

Another economic conflict in the North lies in the enormous cost of development vs the expected return on the money expended. Development (e.g. petroleum development) may have to wait for 20 years or more for financial returns. The amounts, and the interest charges on the amounts, boggle the mind. In the Arctic frontier, the financial return must be the more certain, or of greater value, or possibly the development must be of greater strategic importance.

The moral, demonstrated by the Alaskan experience, is: conflicts with northern people must be recognized and we must come to come to a mutual understanding so that long delays can be avoided.

CONFLICTS IN SCIENCE

Several areas of conflict, some wholesome in nature and others less so, can be noted: (1) the historical conflict between the colourful adventurer and the plodding scientist; (2) the rush for 'empire' (territorial or scientific), at the expense of good work and progress; and (3) conflict between the demands of time and resources for teaching vs research.

The conflict between adventure and science has been with us for a long time. The early travellers were all adventurers at heart, even if the excuse for travel at the time was national pride, territorial gain, or even science. Think of Roald Amundsen, a true Nordic adventurer, feeling obliged to learn a useful bit of science (in his case geomagnetics) so that he could justify and raise support for his adventures. It was pretty thin support: on one occasion he had to get under way surreptitiously to avoid creditors who were about to seize his ship! Today, real adventurers can climb mountains or cross the Arctic Ocean, either using their own resources or raising money through promises to publish books or newspaper articles. But even today the old idea reappears that it is more respectable, or supportable, if a little 'science' is done (see Cochran, this volume). Perhaps, however, when you get down to it, institutional scientists are nothing more than closet adventurers masquerading as scientists!

One of the more notorious clashes between adventure and rock-steady science in Arctic Canada occurred during the government-sponsored Canadian Arctic Expedition. The Director of the Geological Survey of Canada in 1913, when the expedition departed, was R.W. Brock, a man who had guided the Survey to its present tradition of high scholarly and scientific standards. The Survey had assigned several field men (J.J. O'Neill, K. Chipman, J.R. Cox, and G.S. Malloch) to the project, and they were to be directed in the Arctic by R. M. Anderson, who had been a companion of Stefansson in earlier work. A regular, systematic scientific program was envisaged. This approach, however, contrasted with the more dashing one of Stefansson, whose style was to travel widely, live off the country, and be guided by the migrations of natives and game. A great setback occurred when the main expedition ship, the *Karluk*, was lost. Stefansson's determination to carry out his planned northern exploration in spite of the loss of people and materiel resulted in considerable tension among expedition members in the field. In the end, both Stefansson's and the scientific goals were achieved, but at the expense of years of controversy and bitterness following the return of the expedition in 1918 (Zaslow 1975).

One expedition, however, that did combine the best of adventure with the best of science was Sverdrup's voyage aboard *Fram* into the Arctic Islands. The tough Norwegian crew travelled prodigiously for several years, had many adventures and saw much "New Land", at the same time accomplishing a great deal of science. The geological results alone put the expedition in a rank by itself, not exceeded until modern times and helicopter-supported projects (Dawes and Christie 1986).

The conflict between university teaching and research roles is necessarily blurred at more advanced levels of study, as the student and teacher collaborate in useful work. A traditional feature of the Geological Survey of Canada is worth noting: the hiring of junior and senior students as assistants for field work provides invaluable field-training and experience. This is usually an example of cooperation, except for rare occasions when the roll of the dice results in a totally green, accident-prone crew that puts an end to all hope of success. Then we have conflict!

An interesting aspect of conflict in science only occasionally applies to the North: the conflict between directors of science and the working scientists. A working scientist, typically an outstanding one, rises to direct his peers and discovers that the pressures and responsibilities of his new role are added to the earlier, habitual pressures of a scientist. Should he or she be a 'nice guy' or a 'driver'? W.A.S. Sarjeant (1986), in a book review, noted that "... it is the tyrannical and unloved Directors [of the British Geological Survey] who achieved most in research ... whether personally or through the work of their minions". Think about it!

CONCLUSIONS

Generally speaking, healthy, hearty conflict in the North is good for all concerned. It keeps us awake, and keeps us (more or less) honest because the conflict creates what can be called 'noise', and others become more interested in what is happening.

Is the situation altogether too calm in our North? I think not: both continuing and new conflicts are evident, as described here. Furthermore, I think we should carry on as we are doing, with a little conflict here and a little cooperation there, all with spirit and in good humour!

REFERENCES

Amundsen, R. 1927. My life as an explorer. Doubleday. Page & Company, Garden City, New York. 282 pp.

Anonymous. 1980. Arctic Pilot Project: Petro-Canada, Calgary. (Pamphlet).

______. 1982. Greenland united against Arctic Pilot Project. Greenland Home Rule Information Service, TUSARLIIVIK, Nuuk, Greenland.

______. 1983. IWC continues bowhead quota: In: Arctic Policy Review. Barrow, Alaska, September, 1983.

Bach, H.C. and J. Taagholt. 1977. Greenland and the arctic region - in the light of defense policies; defense aims. Information and Welfare Service of the Danish Defense (Forsvarets Oplysnings-og Velfaerdstjeneste), Copenhagen, Denmark.

______. 1982. Greenland and the arctic region - resources and security policy. Information and Welfare Service of the Danish Defense (Forsvarets Oplysnings-og Velfaerdstjeneste), Copenhagen, Denmark.

Brochu, M. 1970. Les expéditions motorisées au Nouveau-Québec: une ouverture d'avenir pour la science et l'économie: Hydro-Québec, Force 10:27-35.

Butters, T. 1973. Visitors North: development of a tourist industry in the Northwest Territories. In: Arctic Alternatives. Edited by: D.H. Pimlott, M.V. Kitson, and C.E. McKnight. Canadian Arctic Resources Committee, Ottawa. pp. 131-142.

Davids, R.C. 1982. Lords of the Arctic. Macmillan Publishing Company, New York. 140 pp.

Dawes, P.R. and R.L. Christie. 1986. Per Schei (1875-1905). Arctic Profiles. Arctic 39:106-107.

Greene, M.T. 1982. Geology in the nineteenth century: changing views in a changing world. Cornell University Press, New York. 324 pp.

Griffiths, F. 1983. Arctic Third World: indigenous people and resource development. In: Arctic Energy Resources. Edited by: L. Rey. Cold Regions Science and Technology 7. Elsevier, The Netherlands. pp. 349-355.

Hamelin, L.-E. 1970. Nord-canadien, ou est-tu? Hydro-Québec, Force 10:37-41.

Larsen, H.A. 1958. The North-West Passage 1940-42: the famous voyages of the Royal Canadian Mounted Police "*St. Roch*". Queen's Printer, Ottawa. 51 pp.

Nicholson, N.L. 1954. The boundaries of Canada, its provinces and territories. Mines and Technical Surveys, Canada, Geographical Branch, Memoir 2:1-142.

Sarjeant, W.A.S. 1986. Book review of "Down to Earth. One Hundred and Fifty Years of the British Geological Survey". Geoscience Canada 13(4):280.

Sollie, F. 1983. The developing Arctic. In: Arctic Energy Resources. Edited by: L. Rey. Cold Regions Science and Technology 7. Elsevier, The Netherlands. pp. 357-361.

Sugden, D. 1982. Arctic and Antarctic, a modern geographical synthesis. Basil Blackwell, Oxford. 472 pp.

Sverdrup, O. 1904. New land - four years in the Arctic regions. Longmans, Green, and Co., London. Volume I, 496 pp. Volume II, 494 pp.

Vanderzwang, D.L. and C. Lamson. 1986. Ocean development and management in the Arctic; issues in American and Canadian relations. Arctic 39:327-337.

Zaslow, M. 1975. Reading the rocks; the story of the Geological Survey of Canada, 1842-1972: MacMillan, with Energy, Mines and Resources and Information Canada, Toronto. 599 pp.

Illustrated by Brenda Carter

SCIENTIFIC RESEARCH IN THE CANADIAN ARCTIC ISLANDS - THE FUTURE

E.F. Roots[1]

Abstract: The Canadian Arctic Islands (the northern fifth of Canada) present a remarkable diversity of natural phenomena, some unique features and a surprising richness in human history. The main driving forces for research in these islands appear to be: defence and sovereignty, environmental protection, resource development, social and political development, and global scientific questions often leading to participation in major international research programs. New research techniques (e.g. remote-sensing and automatic instrumentation) can be expected to find early use in the Arctic Islands, where study areas are hard to reach and field expenses are high. Scientific studies in the region are shifting from descriptive observations to research on processes, and causes and effects of observed phenomena. In future there will be greater emphasis on multidisciplinary, internationally-related research. If certain challenges to scientific progress can be overcome by long-term solutions, then rather than being "Canada's missing dimension", the Arctic Islands will add an extra dimension to science in Canada.

Résumé: Les îles de l'Arctique canadien (le cinquième du territoire) présentent une remarquable variété de phénomènes naturels, des caractéristiques uniques et une richesse insoupçonnée en vestiges de l'histoire de l'humanité. Les principaux moteurs de la recherche dans les îles sont : la défense et la souveraineté, la protection de l'environnement, la mise en valeur des ressources, le développement social et politique, et des préoccupations scientifiques globales impliquant souvent la participation à d'importants programmes de recherche internationaux. Les nouvelles techniques de recherche (comme la télédétection et les appareils automatiques) trouveront leurs premières utilisations dans les îles de l'Arctique canadien, où il est difficile de se rendre dans les zones d'étude et où les expéditions sont onéreuses. Les études scientifiques dans la région s'éloignent des observations descriptives pour aborder la recherche sur les processus, et sur les causes et effets des phénomènes observés. Dans l'avenir, on s'attachera encore plus à la recherche multidisciplinaire de portée internationale. Si on peut surmonter certains obstacles au progrès scientifique, à la longue, les îles de l'Arctique ne seront plus la grande inconnue du Canada, mais au contraire ajouteront considérablement à nos connaissances scientifiques.

INTRODUCTION

The general reviews and the more specialized papers in this volume give a picture of the present knowledge and research projects in the Canadian Arctic Islands in a wide range of scientific fields. These contributions show that although there are many distinctive aspects to research in the Far North of Canada, scientific knowledge about the Arctic Islands is nevertheless an integral part of the organized knowledge of all of Canada and indeed of the world. Seen in this light, the Arctic Islands present a remarkable diversity, some unique features, and a surprising richness.

No one who studies the Arctic Islands can fail to be impressed by the *diversity* of natural phenomena and in northernmost fifth of Canada, the *uniqueness* of many of its characteristics, on land, in the surrounding waters, and in the atmosphere; and the surprising *richness* of its human history.

---

[1] Canadian Environmental Advisory Council, Environment Canada, Terrasses de la Chaudière, Hull, Québec K1A 0H3

These papers embody the results of past research and discovery. And the history of that research and discovery is quite long. Although, as Robert McGhee (this volume) relates, people have been living in the Canadian Arctic Islands off and on for the past 4,000 years, our present knowledge derives very little from the knowledge of these earlier people. A remarkable awareness of the geography, including details of topography and oceanography, the environment and some aspects of the biology of much of the Arctic Islands is an integral part of the consciousness and the mental image of their surroundings of living Canadians whose ancestors have occupied the archipelago and northern mainland for the past 40 generations or so. But little of that awareness has passed directly to other Canadians who lived farther south in Canada, or whose forebears arrived more recently from other lands. Western man is undertaking research today to find out about the first human inhabitants of the Arctic Islands as objects of study, rather than building on *their* base of knowledge.

Except for the awareness inherited by those of us who are Inuit, our present formal ideas and understanding of the Arctic Islands appear to have begun with Leif Erikson about 1000 AD and by Karlsefni about 1010, who brought into European knowledge descriptions of Helluland (land west of Greenland characterized by smooth slabs of rock topped by a glacier). Probably Helluland is southeastern Baffin Island. The first representation of the Canadian Arctic Islands on a map, that we know about today, was drawn by Johannes Rysch of the Netherlands in 1507, who showed four islands west of Greenland and surrounding the North Pole. Rysch wrote on his map that he got the information from a book published more than a century earlier reporting Norwegian and English travels or legends. This information became widespread, and was included on several other maps, notably those of Lok, Ortelius, and Mercator, before Martin Frobisher in 1576 made the first documented voyage by a European to the Canadian Arctic Islands (Weber and Roots, this volume). Within the next 340 years the geography of the archipelago became fairly well charted; but it was not until 1947 that the last large islands, Prince Charles Island and Rowley Island, were added to the map, and in 1961 we made the last major correction to the map by moving Meighen Island to its proper location. So there is a long history of the gradual evolution of knowledge of the region.

I intend not to assess present knowledge or research, but to ask you to think about the future. Where is the present research taking us? What kinds of scientific problems are emerging as the most important? Who will be doing the research in this area in the future, and what techniques will they use? And, very important, who will be sponsoring that research, and why?

The diversity and uniqueness of the Canadian Arctic Archipelago make the study of its natural features, its resources, and its history of great scientific importance and interest, not only for the understanding of the region for its own sake and its future development or protection, but also because understanding of the natural processes that occur there is important to world science, to many national issues, and to international relations. Modern study of the Canadian Arctic Islands has a significance that goes beyond finding out a bit more about a little-known part of the country.

If we are to consider the directions that scientific research in the Canadian Arctic Islands is likely to take in the future - in the light of the current research being described in this volume - we should step back from the detailed accounts of current scientific activities, and ask:

(1) What basic features make the Canadian Arctic Islands distinctive or scientifically important?
(2) What kinds of scientific problems are being addressed today? In which problems or subjects is our knowledge approaching maturity, and what new areas are emerging as high priority?
(3) Who is addressing these problems and why? What do the researchers hope to find, or to find out?
(4) What is the importance of the new knowledge being sought? To whom is it important?
(5) What other studies, in different regions, are important to our research in the Arctic Islands, and vice versa?

If we can think about these and other questions to get a mental picture of some of the important characteristics of the islands and the reasons for the present studies, we will have a better basis for speculation about future research.

BASIC FEATURES OF THE CANADIAN ARCTIC ISLANDS

This is not the place for a description of the geography or the scientific features of the Canadian Arctic Islands; but let me remind you of a few varied facts that may be important to an appraisal of where research in this complex area is heading, now and in the near future.

Geography

The Canadian Arctic Islands comprise about 20% of Canada's land area. If you include the islands in Hudson Bay, they cover about 30 ° of Latitude; a north-south distance roughly equal to the distance from Ottawa to Guatemala. Most of the islands, however, lie north of the Arctic Circle, in a triangular mass that, if it were transposed to southern Canada, would cover the land between Vancouver, Sault Ste. Marie, and Yellowknife. So we are talking about a large chunk of country! It is a country that ranges in scenery from flat, nearly featureless desert - Banks Island is my candidate for one of the most monotonous large pieces of land anywhere on Earth, not counting the interior of Antarctica or Greenland, to walk or ski across - to spectacular fiords and steep, glacier-hung mountains that attract enthusiastic mountaineers from all over the world (Cochran, this volume). Understanding, or even describing this varied land and the marine waters that cut through it and surround it, is a scientific challenge in itself.

Geophysics

The Arctic Islands contain the North Magnetic Dip Pole which is now somewhere off northern Bathurst Island and moving north a few kilometres each year. That's where the compass needle stands on end, as the lines of magnetic force are vertical. The geomagnetic pole, which is the north pole point of the magnetic field generated by the Earth spinning in space like a big magnet, is also in the Canadian Arctic Islands, on Ellesmere Island. These magnetic phenomena make the region especially important for geophysical and space studies (critical to planetary science and applied sciences ranging from communications to prospecting for minerals), which can be carried out nowhere else.

Environment

The high latitude of the islands means that solar energy is received at a low angle, and for part of the year there is no direct solar radiation at all. The net energy received from the sun at Resolute, near the middle of the archipelago, is only about one-seventh that received at Toronto. The results are familiar to everyone concerned with the Arctic: (1) low temperatures; (2) water on the surface, in the ground, in the air and in plant tissues is, throughout the year most commonly solid (ice or snow) rather than liquid (ordinary water or vapour); (3) most of the solar energy received in spring and summer is used to melt ice or snow, not to raise temperature (see McKay, this volume). In most of the archipelago, the lands or waters are only free of snow and ice and can begin to get warm and support life long after midsummer, so that growth can take place only while the sunlight is getting weaker and the days are getting shorter. Special forms and communities of life have had to develop to live under these trying conditions - on both land and at sea (e.g. see Connover *et al.*; Bliss; Danks, this volume).

Geological History

The Arctic Islands have not always had the global position or the environmental conditions they have now. They are migratory land masses. The presence of coal, petroleum, fossil coral reefs and dinosaur bones (Russell, this volume) testify to a different history and different climates in the past - and give a potential economic importance to the region that it would not have, had it always been as we find it today. As Mary Dawson (this volume) points out, at least since Tertiary times the islands have been in arctic latitudes; but for most of even that time the climate was more temperate than it is today. Not only did lower sea level produce a Bering Isthmus, but a milder climate gave many animals who do not now live in the Arctic something to eat as they wandered across this land connection.

Modern Changes

Although few people live on the islands today, they are by no means unaffected by modern human activities. The once clear air now carries a distinctive "arctic haze" whose origin is in industrial smokestacks in the temperate zone (McKay, this volume). Polar bears and whales in the archipelago carry in their livers chemicals that were sprayed on fruit trees and cotton fields far to the south. Icecaps on Devon Island and Ellesmere Island (Koerner, this volume) faithfully record global pollution, year by year, and show the distinctive changes caused by industrial expansion during the present century. And all indications are that the rapid world-wide climate change, which may be expected during the next century because of accumulation of man-made greenhouse gases in the atmosphere, will have its greatest effect in the zone between 60 and 75°N - which includes most of the Arctic Islands.

Geopolitics

The Arctic Islands are the part of Canada facing the Soviet Union across the Arctic Ocean. Alert is almost twice as close (2,400 km) to the Soviet nuclear test-site on Novaya Zemlya or the ICBM silos on the Kola Peninsula as it is (4,700 km) to the North American Air Defense Command ICBM silos in North Dakota. Thus the geography of the Arctic Islands becomes a key element in global military and peace-keeping strategies. This situation, no less than the low temperatures or the potential petroleum deposits, is one of the basic features of the Canadian Arctic Islands today.

Results of Basic Features

The net result of basic natural conditions noted above is the diversity, uniqueness and richness that characterizes the Arctic Islands today: arctic weather; long polar summer days and long winter nights; the aurora; permafrost; vistas of prolific flowers in summer and wind-driven snow in winter; sea ice; icebergs off the east coast and ice islands in the Beaufort Sea. And low-energy ecosystems, short food-chains with remarkable adaptations of individual species and biological communities. Muskoxen; caribou; lemmings; arctic wolves; Snow Buntings and Snowy Owls; seals, walruses, polar bears. Oil, gas, coal and metals, although how much and whether the deposits are really worth anything in net economic terms may be uncertain. A short shipping-route between London and Yokahama; a short flying-route between Moscow and Los Angeles.

These are some features of the Arctic Islands today. All these are why the islands and surrounding waters are important for current scientific study. Based on the knowledge we now have, this importance is almost certain to increase in the next couple of decades.

THE IMPORTANCE OF SCIENTIFIC KNOWLEDGE OF THE ARCTIC ISLANDS

Forces Driving Research

To whom is scientific knowledge of the Arctic islands and waters important? To most scientists, to historians, and to those concerned with our natural heritage for its own sake, this question does not have much meaning. Of course the knowledge is important, if it is valuable and available to all. We are fortunate in having a National Museum of Natural Sciences and a Canadian Museum of Civilization that can continue research programs, even though modest and often carried out with insufficient funds, whose principal objectives are to increase knowledge of our arctic heritage. But, whether we desire it or not, most science in the world today - and certainly in Canada - is undertaken to fill a more closely defined policy-mission or practical objective. If we wish to look at the future of research in the Arctic Islands, we should consider the main driving forces for research support in northern Canada generally, and consider how these apply to the archipelago.

The main driving forces are easy enough to identify. All one has to do is to review present expenditures for arctic research, note who is spending the money and why; and to review the arguments put forward by the scientists themselves, or their bosses, as to why they should be funded to carry on research in which they are particularly interested. Many research studies contribute to more than one need or objective; but outside the studies funded by the National Museums and a few private institutions, the main "driving forces" for research in the Arctic Islands today and in the years ahead appear to be as follows:

Defence and Sovereignty

If Canada is the ham in the U.S./U.S.S.R. superpower sandwich, the Arctic Islands is the mustard on top of the ham. All defence-related arctic surveillance and monitoring systems, in the atmosphere and in the waters beneath the ice, require an increasingly sophisticated knowledge of the archipelago. And, from a purely Canadian viewpoint, we are well aware that the deep-draught North-West Passage (a key element in our sovereignty concerns) runs right through the middle of the Arctic Islands. These various issues translate to a higher priority for research in fields of ionospheric geophysics, aeronomy and magnetism, physical and biological oceanography, hydrography, sea-ice studies, meteorology and climatic studies, as well as high-latitude communications.

Environmental Protection

High on the list of Canadian priorities for undertaking arctic research, in terms of the funding that comes from a variety of sources, is protection of the natural environment. The Arctic Islands play a prominent part in northern environmental studies, both because land and sea environmental characteristics of the archipelago are sensitive to disturbance from a number of causes (so better understanding of environmental processes is needed if effective protection measures are to be applied), and because study and monitoring of the extreme environment of this area can be useful and important to environmental protection and control over a large part of the northern hemisphere. Subjects most important for these studies are: climatology; geomorphology; terrestrial, aquatic and marine biology; environmental biogeochemistry and toxicology; and various pollution-control and cleanup technologies.

Development of Resources

A great deal of the increase of research in the Arctic Islands in the past 25 years has been connected with, or spurred by, the indications of deposits of non-renewable resources and the expectation that, with sufficient knowledge and adequate technology, those resources could be exploited at a profit. The work has achieved a measure of success - two base-metal mines and a small oilfield are now producing in the Arctic Islands. But the drop in prices for both metals and petroleum on world markets, combined with high interest rates and steadily rising costs for arctic industrial operations, have sharply reduced earlier optimistic hopes that the region could become a major generator of local or national wealth in the near future. Along with this more sober picture has come a change in research priorities: attention to a variety of renewable and non-renewable resources and their management; smaller-scale balanced development and the attendant lower-cost technologies; the "geographical service functions" of transportation, communications, and tourism; and greater attention to the historical and natural heritage, as well as local concerns (Hobson, this volume). Many of these changes, and the new areas of basic, applied and management research needed to realize them, are already being reflected in the papers presented in this publication.

Social and Political Development of Northern Regions

In many parts of Arctic Canada, one of the principal causes of change in the character and subject of research has been the political evolution of the northern territories, and the changed needs, awareness and decision-making power of northern peoples themselves. Studies in social sciences and applied fields undertaken according to the priorities of northern residents are still relatively rare anywhere in the North but are increasing, and can be expected to increase still more in the near future. The Arctic Islands have been part of this change, and indeed have been the locale of much research undertaken for and by the Inuit in connection with the discussions on creation of the territory of Nunavut. Such studies include resources inventories; health sciences; community planning and management; research into educational methods; history and archaeology. George Hobson (this volume) has given us a spirited account of the need for future arctic research to be managed to a greater extent by northerners themselves.

One element of the researches undertaken in connection with northern socioeconomic development is the degree to which the studies have an international or circumpolar character, and yet are closely tied to local concerns. All countries around the Arctic Ocean are undergoing political and institutional changes in their northern regions, and the resident northerners are asking for, and in many cases receiving, a greater say in decisions affecting their lives (Christie, this volume). In doing so, they are developing new knowledge. The Canadian Arctic Islands provide a part of that knowledge. The circumpolar northern peoples have developed a communication network to share information and the results of one another's investigations. In this respect they lead the governments of the various arctic nations.

Global Scientific Questions

Some of the most exciting research likely to be carried out in the Arctic Islands in the next couple of decades will be that connected with major international multi-disciplinary research programs. As the northernmost extension of ice-free land in the world, the Canadian Arctic Archipelago is important to many studies of world-wide phenomena. Its unique geophysical, geological, climatic, oceanographic and biological characteristics have meant that the Arctic Islands have played a prominent role in past major world-wide researches, such as the International Polar Year, the International Geophysical Year, the International

Biological Program, the International Magnetospheric Study, and many more. Similarly, these islands figure prominently in the new wave of international world-wide studies now being launched: the International Geosphere-Biosphere Program, the World Climate Research Program, the International Lithosphere Project, the Man and the Biosphere Program, and others. These studies will, if fully developed, bring a wide range of physical, biological and human sciences in the Arctic Islands into close contact with advanced studies in similar subjects in other parts of the world.

NEW TECHNOLOGIES

One of the most striking differences between the researches that can be expected in the next few years in the Arctic Islands and those of the past couple of decades is the difference in research technologies. While the field-scientist traversing on foot or helicopter and making detailed visual observations or simple measurements is not yet a relic of the past, it is increasingly true that in nearly every research subject the advanced research is becoming more instrumented, technological, and quantitative. New technologies not only make possible more precise measurements and investigation of much more sophisticated phenomena than was possible before. They also often offer considerable saving in field costs, and increase scientific productivity per scientist-day in the field compared to older methods. Further, they make it almost mandatory that the leading research, even in the Arctic, be based in a technically-advanced and well-funded institution in lower latitudes. The new research techniques can be expected to find early use in the Arctic Islands, where costs for field work are already the highest in the country.

In many fields, important arctic problems can no longer be adequately studied in the summer or in areas easily reached. To study processes on a year-round basis, in the marginal ice zone, during severe storms or ice break-up requires specialized and often very sophisticated equipment. Thus satellite surveys, various forms of remote-sensing, automatic instrumentation with telemetered observations, sophisticated portable field-laboratories and computers can be expected to become a conspicuous part of Arctic Islands science in the years ahead.

With these changes in technology must come, of course, a change in the type of scientists that work in the Arctic Islands, and in the training that they undergo in the laboratory and in the field. It requires a rather different kind of scientist to sit on a rocky perch for hours recording the mating habits of a polar bear than one who measures the fat-content of the milk of a lactating bear by electrical conductivity, although some scientists can make and, indeed, lead the change. Inevitably, such changes lead to alteration in the way that research projects are formulated and the results evaluated. Research technology not only determines the way in which we seek new knowledge; more than we often realize, the technology determines what knowledge we seek - and find.

For those of us who started research in the Arctic Islands in the dog-team era, things are becoming quite different. It is easier in the field today; no sense in pretending otherwise. And in many ways it is harder - harder to be sure that one is really adding significantly to new knowledge. But the interests, satisfactions, frustrations and fun are all still there.

TRENDS IN SCIENCE

Recent reviews of research programs and individual studies in the Canadian Arctic have shown clear trends in the orientation and scope of the science being pursued. These seem to be typical of nearly all fields of study.

In the Canadian Arctic Islands, although there are many areas in many subjects where data are inadequate and careful observations are few or absent, the descriptive phase (in which the scientist recorded as accurately as possible what was there) has to a great extent been replaced in both natural and social sciences by studies of processes (natural or induced by humans), or of causes and effects of observed phenomena. The emphasis today is not so much on what is there, but on how things got the way they now are, and what changes are currently taking place. These new emphases in turn are leading to a focusing of research on major scientific problems, such as climate change and the migration of vegetation zones (Edlund, this volume), the flow of chemicals through an ecosystem, or the reasons for changes in animal or human populations. As a result - and this is probably influenced by budgets and institutional factors and technologies, as well as by the needs and opportunities of the science itself - we are seeing more team research. Different disciplines are joining to work on related aspects of the same problem, and there is a closer integration of arctic studies with studies in the rest of the world.

Although much of the emerging research is international in outlook and criteria, the broader context need not mean that the new research is less relevant to local problems. Indeed, international connections in arctic research can serve to bring the knowledge of world science to bear on the distinctive problems of the Arctic Archipelago or its people, as well as to make a contribution from the Canadian Arctic to important problems being studied in other parts of the world.

SOME PROBLEMS

Problems can be foreseen regarding research in general in the Arctic Islands, to which serious attention should be given in the years ahead. Likely, future research in the archipelago will be *even more closely linked to policy priorities* than at present, and this may increase the difficulties of maintaining a balanced advance of knowledge across a wide range of subjects important to an understanding of the region. As a recent study (Adams *et al.* 1987) has shown, Canada urgently needs: (1) *a means to ensure continuing attention and resources for arctic science*; (2) a means for developing *research programs reflecting the priorities of the North* as well as southern Canada; and (3) an effective *polar science information-system*. These needs apply to the Arctic Islands as well as other parts of northern Canada.

Special care may be needed to *integrate or reconcile local priorities for new knowledge with the broader research requirements of international programs*. The high cost and technical sophistication of modern arctic research pose special challenges to the *full participation of northern residents* in planning and conducting research in their own hinterland, and to providing Arctic Islands *research experience to significant numbers of students*.

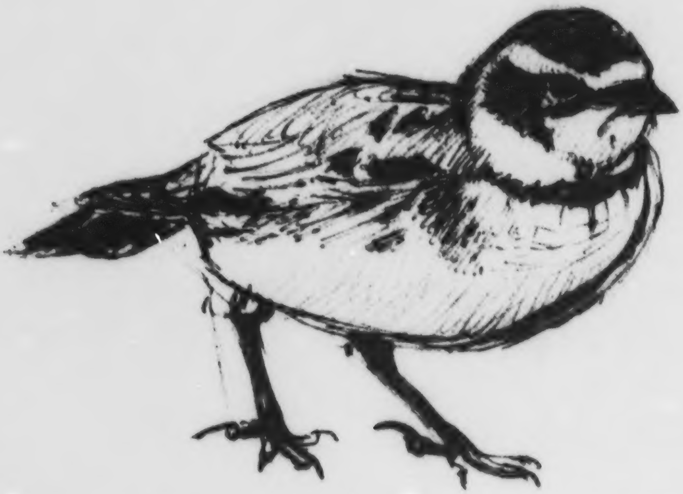
It is important that these challenges be met, and that the Canadian Arctic Islands yield in future not only knowledge that is of vital national and international importance, but that the islands play a leading role in the practice and the relevance of Canadian science.

If the challenge can be met, then rather than being Canada's missing dimension, the Arctic Islands will add an extra dimension to Canadian science.

REFERENCE

Adams, W.P., P. Burnet, M.R. Gordon, and E.F. Roots. 1986. Canada and polar science. Indian and Northern Affairs Canada, Ottawa. 129 pp.

Illustrated by Brenda Carter



Illustrated by Brenda Carter

THE EARTH: FOSSILS AND PALEOENVIRONMENTS

Illustrated by Brenda Carter

PALEOZOIC FISHING - THE FRANKLINIAN GROUNDS

D.L. Dineley[1]

Abstract: The Silurian and Devonian rocks of the Arctic Lowlands around Barrow Strait include formations mostly of shallow marine and continental origins. From a large number of Late Silurian and Early Devonian horizons many agnathan and a small number of gnathostome fishes are known. All the major heterostracan families occur, as do a few cephalaspid species. The anaspids occur early in the sequence but are rare: thelodonts have been found at levels ranging from Early Silurian to Early Devonian in both marine and continental facies. Acanthodian fishes range from mid-Silurian to the top of the local Lower Devonian, and arthrodires occur in the highest levels. The most advanced fishes were the "porolepid" osteichthyans - relatively large forms.

The agnathan cyathaspids, traquairaspids and pteraspids appear to be especially well represented both in numbers of species and individuals. The small protopteraspids are held to originate from small cyathaspids, and subsequent pteraspid evolution was rapid. All of these agnathans are biostratigraphically valuable.

These vertebrate faunas have much in common with their early Devonian contemporaries in Spitsbergen and northwestern Europe, as well as with other regions of North America. This Euramerican province is distinct from those of Siberia, China and Australia.

Résumé: Les roches siluriens et dévoniens des basses terres de l'Arctique autour du détroit de Barrow comprennent des formations qui sont principalement d'origine continentale et marine peu profonde. De nombreux poissons agnathes et quelques gnathostomes ont été identifiés dans un grand nombre d'horizons du Silurien supérieur et du Dévonien inférieur. Toutes les familles principales des hétérostracés s'y retrouvent, tout comme quelques espèces céphalaspides. Les anaspides sont présents au début de l'ère, mais ils sont rares: dans les faciès marins et continentaux, on a trouvé des thélodontes à des niveaux variant du Silurien inférieur au Dévonien inférieur. Les poissons acanthodiens se retrouvent à partir du Silurien moyen jusqu'à la fin du Dévonien inférieur local, tandis que les arthrodires sont dans les niveaux supérieurs. Les poissons les plus évolués étaient les ostéichtyens "porolépides", des formes relativement grosses.

Les cyathaspides agnathes, les traquairaspides et les ptéraspides semblent être particulièrement bien représentés en nombre d'espèces et de spécimens. On considère que les petits cyathaspides dérivent des petits protoptéraspides, et que l'évolution subséquente des ptéraspides fut rapide. Tous ces agnathes ont une importance biostratigraphique.

Ces faunes de vertébrés ont beaucoup en commun avec leurs contemporaines du Dévonien inférieur au Spitsberg et dans le nord-ouest de l'Europe, de même que dans d'autres régions de l'Amérique du Nord. Cette province euroaméricaine est distincte de celles de Sibérie, de Chine et d'Australie.

INTRODUCTION

Since the late 1950s, an increasing number of primitive fossil vertebrates has become known from the Palaeozoic formations of the Canadian Arctic Lowlands (Figure 1). Locally they occur abundantly and represent assemblages of the jawless fishes with minor numbers of other extinct species, including the earliest gnathostomes. The enclosing sedimentary rocks range from early and mid-Palaeozoic marine carbonates to Devonian carbonates and continental red-bed clastics. For over 100 years mid-Palaeozoic vertebrates have been known in Europe and in North America, puzzling the palaeontologists of the day and being variously ascribed to different taxonomic groups. The Canadian materials provide some excellent insights into the anatomies of these ancient and extinct animals and into the environments in which the creatures lived. It is also clear that, in company with similar contemporary forms in Europe and Spitsbergen, they were members of a distinct early Devonian biological province some 375-390 million years ago. Contemporary provinces in other parts of the Devonian world, namely Siberia (Angara), China, and Australia-Antarctica (East Gondwana) were inhabited by other early, and presumably primitive, aquatic vertebrate groups. These separate provinces lasted for about 15 million years, by which time most of the agnathous forms achieved a wide geographical range and widespread success before abruptly declining. The fossils from the Silurian and Devonian formations of the District of Franklin, Arctic Canada, illustrate both the rapid and successful development into new local environments and the rapid evolution of several anatomical variations. The picture becomes clearer and more intriguing when the geography of those distant times is taken into account.

---

[1] Department of Geology, University of Bristol, Bristol BS8 1RJ, U.K.

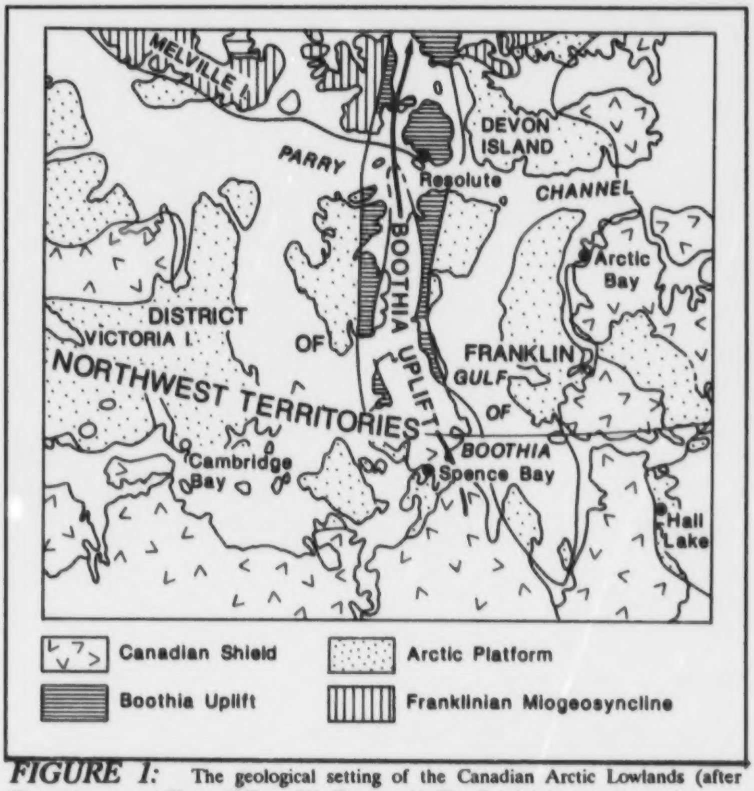

MELVILLE I.
PARRY
DEVON ISLAND
Resolute
CHANNEL
BOOTHIA UPLIFT
Arctic Bay
DISTRICT OF FRANKLIN
VICTORIA I.
NORTHWEST TERRITORIES
GULF OF BOOTHIA
Cambridge Bay
Spence Bay
Hall Lake
Canadian Shield
Arctic Platform
Boothia Uplift
Franklinian Miogeosyncline

FIGURE 1: The geological setting of the Canadian Arctic Lowlands (after Thorsteinsson and Tozer 1970, p. 550, Figure x-1). The Franklinian miogeosyncline was the deeper water basin lying to the north of the mid-Paleozoic platformal sea. It received predominantly fine clastic sediments, in contrast to the carbonate shelf deposits of the Canadian Arctic Lowlands platform. The Boothia Uplift rose in Late Silurian time to shed its early Palaeozoic cover as a clastic apron onto the platform round about.

The earliest known of all undoubted vertebrates occur in marine formations of Ordovician age, some 125 million years older than those of the early Devonian. Despite the long time-span between these two ages, apparently the vertebrates advanced little in their diversity or complexity. They were shallow-water marine animals throughout that time, well-adapted to modes of life in stable environments, and may have been widely distributed as relatively small populations. The rapid and very important biological changes and events that occurred toward the end of the Silurian period and in the early Devonian profoundly influenced vertebrate evolution (Chaloner and Lawson 1985), and the evidence of this is present in Canada's North as strongly as elsewhere.

Early Silurian vertebrates are uncommon, even in those areas that are most thoroughly investigated. They are, however, known from the Cape Phillips and Snowblind Bay (geosynclinal) basinal succession on Cornwallis Island, and from horizons as low as Llandoverian and Wenlockian. These fossils are fragmentary and poorly preserved, but are in marine successions datable by graptolites. It is clear that they are exotic introductions from shelf areas of deposition elsewhere (Thorsteinsson 1967, 1980).

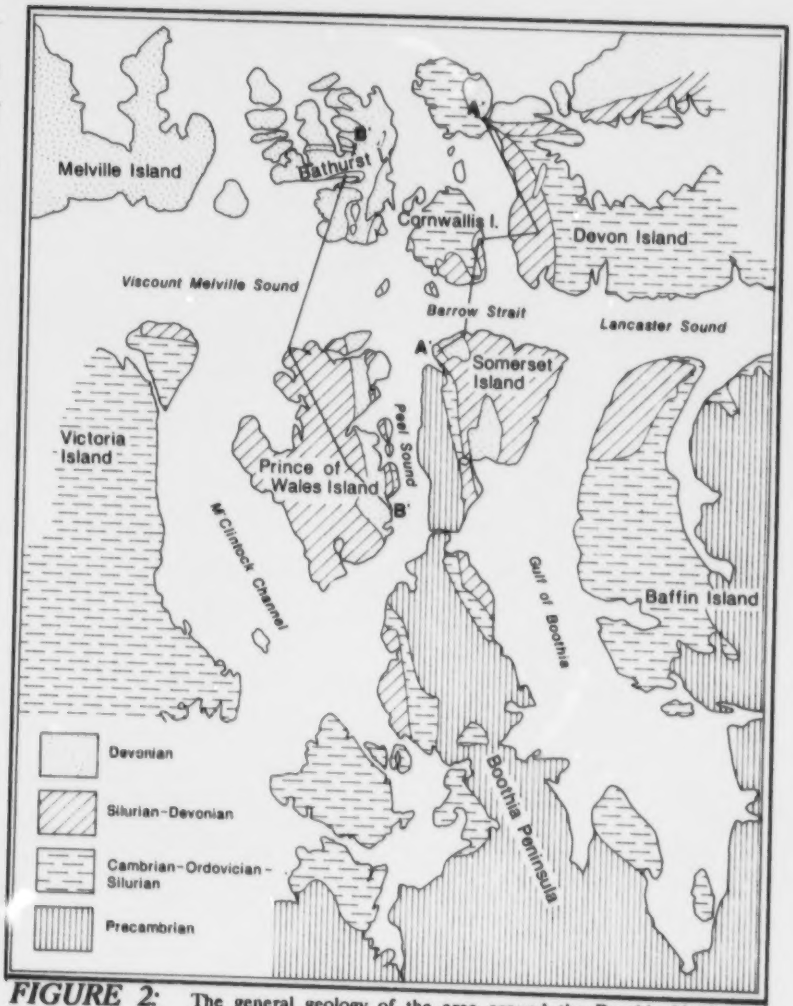

Melville Island
Bathurst
B
A
Cornwallis I.
Devon Island
Viscount Melville Sound
Barrow Strait
Lancaster Sound
A'
Somerset Island
Victoria Island
Peel Sound
Prince of Wales Island
B'
M'Clintock Channel
Gulf of Boothia
Baffin Island
Boothia Peninsula
Devonian
Silurian-Devonian
Cambrian-Ordovician-Silurian
Precambrian

FIGURE 2: The general geology of the area around the Boothia Uplift and Parry Channel (Barrow Strait). The principal vertebrate-bearing formations lie within the Silurian-Devonian and Devonian subdivisions. The sections A-A' and B-B' are shown on Figure 3.

The relatively sudden appearance of vertebrate "provinces" after so long a period of stasis amongst these forms of life coincides in large measure with the introduction into the stratigraphic column of the "Old Red Sandstone" facies as common rock-types. In the vicinity of Barrow Strait and Peel Sound, the Silurian carbonates are succeeded by early Devonian clastic rocks derived from older formations in the Boothia Uplift (Figures 2,3). The region was part of a major continental area known now as 'Laurussia' or the 'Old Red Sandstone Continent' (Figure 10). Early vertebrates were first recognized there by Dr.

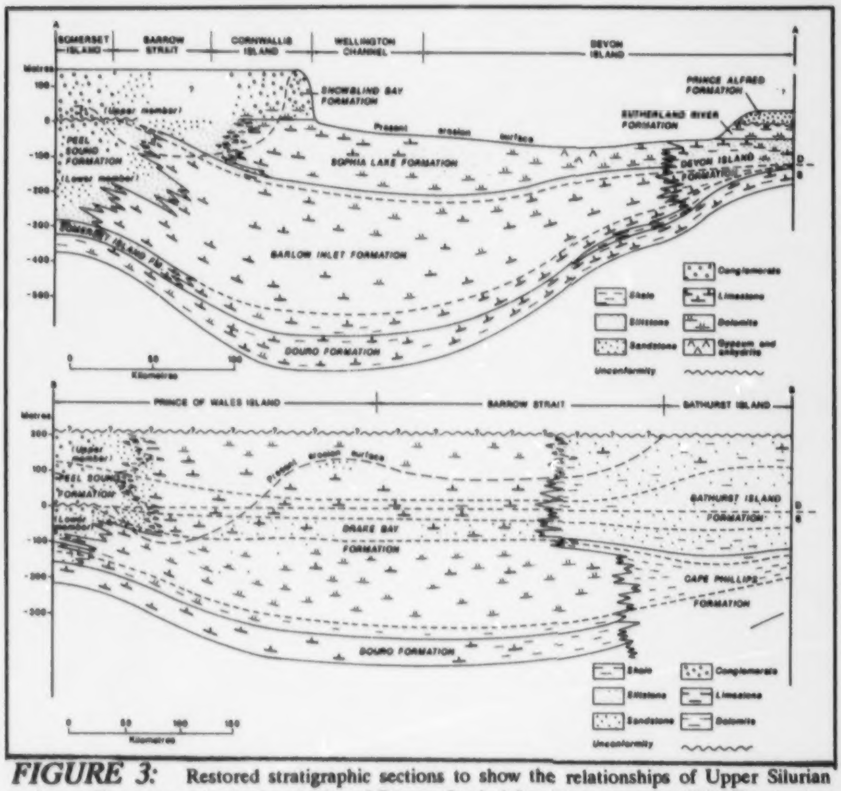

A
SOMERSET ISLAND
BARROW STRAIT
CORNWALLIS ISLAND
WELLINGTON CHANNEL
DEVON ISLAND
A'
Metres
100
0
-100
-200
-300
-400
-500
SNOWBLIND BAY FORMATION
(Upper member)
PEEL SOUND FORMATION
(Lower member)
SOMERSET ISLAND FM.
Present erosion surface
SOPHIA LAKE FORMATION
PRINCE ALFRED FORMATION
SUTHERLAND RIVER FORMATION
DEVON ISLAND FORMATION
D
S
BARLOW INLET FORMATION
DOURO FORMATION
0
50
100
Kilometres
Conglomerate
Shale
Limestone
Siltstone
Dolomite
Sandstone
Gypsum and anhydrite
Unconformity
B
PRINCE OF WALES ISLAND
BARROW STRAIT
BATHURST ISLAND
B'
Metres
200
100
0
-100
-200
-300
(Upper member)
PEEL SOUND FORMATION
(Lower member)
Present erosion surface
DRAKE BAY FORMATION
BATHURST ISLAND FORMATION
CAPE PHILLIPS FORMATION
DOURO FORMATION
0
50
100
150
Kilometres

FIGURE 3: Restored stratigraphic sections to show the relationships of Upper Silurian to Lower Devonian rocks in the vicinity of Barrow Strait (after Thorsteinsson 1980). The broken lines represent the approximate positions of formal biostratigraphic boundaries on the basis of local marine faunas. $\frac{\underline{D}}{S}$ base of the Devonian System. See Figure 2 for map of profiles A-A' and B-B'.

R. Thorsteinsson and the officers of the Geological Survey of Canada in the 1950s (Thorsteinsson 1967 *et seq.*). Subsequent discoveries were made by Geological Survey of Canada geologists and by expeditions from the University of Ottawa over the next two decades, sponsored in large measure by the National Museum of Canada. An impressive volume of material has been amassed - much of it unique. During the same period remarkable similar discoveries have been made in China, Siberia and the Soviet Arctic.

Middle and Late Devonian fishes are present in the successions on Bathurst and other islands northwest of Barrow Strait, but I will confine my comments to the Early Devonian and older formations.

MID-PALAEOZOIC STRATIGRAPHY AND ENVIRONMENTS IN THE BARROW STRAIT REGION

Until Late Silurian (Pridoli) time, much of the region occupied by the islands around Barrow Strait and the Jones-Lancaster Basin was one of shelf-carbonate sedimentation, with deeper water to the north of Cornwallis Island and shallow water and land over the

Canadian Shield (Figure 10). Thereupon the rise of the Boothia Uplift (the Cornwallis Disturbance) produced a finger of land about 800 km long north-south, and 150 km wide. Its core consists of Precambrian crystalline rocks, its flanks are of deformed early Palaeozoic formations within which facies changes occur relative to distance from the Uplift (Brown *et al.* 1969; Kerr 1977; Kerr and De Vries 1976). A summary of the stratigraphy is shown in Figure 3.

The effect of the Cornwallis Disturbance was to create an upland shedding clastic debris to east and west, and bringing about the facies-changes (Figure 3).

These facies-variations may be traced across most of Prince of Wales Island and much of Somerset Island (Broad *et al.* 1968; Miall 1970A; Jones and Dixon 1977) and are known on the islands north of Barrow Strait (Thorsteinsson 1980) in considerable detail. The original broad classification has been much improved (Gibling and Narbonne 1977; Elliott 1983). For example, the Read Bay Formation of earlier accounts is now raised to Group status, its component formations being well identified and of known areal extent. Following are summaries of the principal vertebrate-bearing units now distinguished within the region.

Cape Phillips Formation (Thorsteinsson 1958)

The oldest of the formations yielding vertebrates in this region, it is a thick sequence of Ordovician and Silurian graptolite-bearing argillaceous and carbonate rocks on Bathurst, Cornwallis and Ellesmere islands. It is a lateral equivalent of the Douro and Cape Storm Formations (Figure 3), and it has yielded a few specimens of heterostracan and anaspid fishes (see below for major categories of fishes involved).

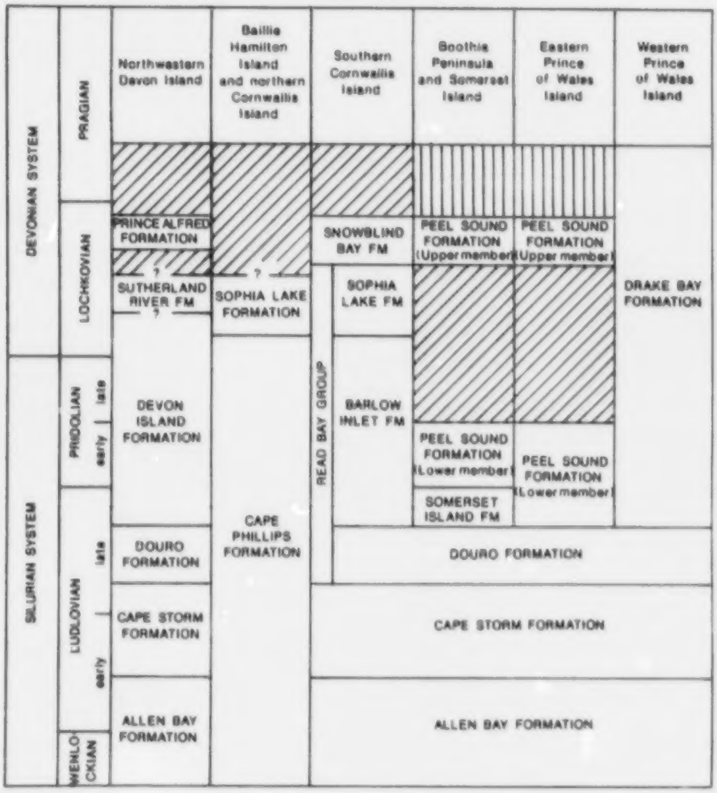
Douro Formation (Thorsteinsson 1963)

This is a thin diachronous late Silurian succession of argillaceous and bioclastic limestones with an abundant shallow-water marine invertebrate fauna. It appears to have been deposited under quiet waters of normal salinity and in two transgressive-regressive cycles. Acanthodian remains occur locally (Narbonne and Dixon 1982).

Cape Storm Formation (Kerr 1975)

This is a very widespread, uniform, homogeneous and thinly-bedded carbonate unit with minor shales. It is as much as 600 m thick on Devon Island but is only 120-260 m thick

TABLE 1: CORRELATION OF STRATIGRAPHIC SUCCESSIONS WITHIN THE BOOTHIA UPLIFT-BARROW STRAIT AREA. OBLIQUE SHADING DENOTES ABSENCE OF STRATA BECAUSE OF UNCONFORMITY IN THE SECTIONS: VERTICAL SHADING INDICATES PRESENT DAY EROSION (AFTER THORSTEINSSON 1980).



			Northwestern Devon Island	Baillie Hamilton Island and northern Cornwallis Island	Southern Cornwallis Island	Boothia Peninsula and Somerset Island	Eastern Prince of Wales Island	Western Prince of Wales Island
DEVONIAN SYSTEM	PRAGIAN		▨	▨	▨	▥	▥	DRAKE BAY FORMATION
	LOCHKOVIAN		PRINCE ALFRED FORMATION ▨ ? SUTHERLAND RIVER FM ?	▨ ? SOPHIA LAKE FORMATION	SNOWBLIND BAY FM READ BAY GROUP: SOPHIA LAKE FM	PEEL SOUND FORMATION (Upper member) ▨	PEEL SOUND FORMATION (Upper member) ▨	
SILURIAN SYSTEM	PRIDOLIAN	late	DEVON ISLAND FORMATION	CAPE PHILLIPS FORMATION	READ BAY GROUP: BARLOW INLET FM	▨	▨	
		early				PEEL SOUND FORMATION (Lower member) SOMERSET ISLAND FM	PEEL SOUND FORMATION (Lower member)	
	LUDLOVIAN	late	DOURO FORMATION		READ BAY GROUP: DOURO FORMATION	DOURO FORMATION	DOURO FORMATION	DOURO FORMATION
			CAPE STORM FORMATION		CAPE STORM FORMATION	CAPE STORM FORMATION	CAPE STORM FORMATION	CAPE STORM FORMATION
		early	ALLEN BAY FORMATION		ALLEN BAY FORMATION	ALLEN BAY FORMATION	ALLEN BAY FORMATION	ALLEN BAY FORMATION
	WENLOCKIAN							

on Somerset Island. Fossils within this formation are generally scarce, but locally there are abundant stromatolites and some brachiopods, bryozoa, corals and stromatoporoids. Conodonts and vertebrates are known from several localities in this unit, which is regarded as shallow marine and dominantly subtidal, but in places and at times intertidal and supratidal.

Somerset Island Formation (Miall *et al.* 1978)

A unit of mainly grey-pink carbonates with variable minor sand, silt and shale members that is 150-300 m thick on Somerset Island, where vertebrate remains (mostly heterostracan, see below) occur both as scattered fragments and as bone-bed accumulations. Brachiopods, ostracods, arthropods including large eurypterids, corals and stromatoporoids are locally abundant, indicating temporary fully-marine conditions; elsewhere sedimentary evidence is for lagoonal and intertidal environments.

Leopold Formation (Jones and Dixon 1975)

A largely dolomitic formation, with stromatolitic limestone and sandy thin-bedded limestones, this unit appears to represent supratidal and high intertidal and lagoonal environments in northeastern Somerset Island. The brachiopod *Lingula* in several beds supports this interpretation. Vertebrates are present as scattered body-plates and isolated scales, probably introduced during storms or other episodes of strong current activity. Possibly this unit is best considered as part of the Cape Storm Formation.

Peel Sound Formation (Thorsteinsson and Tozer 1963)

This is a conspicuous red-bed clastic unit formed mainly of detritus derived from the earliest rocks of the Boothia Uplift. Miall (1970A,B) has described the formation in detail and recognized five facies-belts in the upper of the two members seen on Prince of Wales Island. The environments in which the formation accumulated range from fluvial and alluvial fan to marine farther away from the Uplift. On Prince of Wales Island the marine facies have been designated separately as the Drake Bay Formation (Ormiston 1969) and correlative rocks are known on Cornwallis, Devon and Bathurst islands. Vertebrate remains are common at many levels in all but the coarsest facies (Elliott 1984).

Sophia Lake Formation (Thorsteinsson 1980; Muir and Rust 1982)

Consisting of limestones and dolostones with minor siltstone and sandstone, the Sophia Lake Formation is thought to be a shallow-water possibly intertidal unit (Gibling 1978). Acanthodian scales and spines are known.

Barlow Inlet Formation (Thorsteinsson 1980)

Members B and C of the Read Bay Formation on Cornwallis Island described by Thorsteinsson (1958) were later relegated to this unit. They consist principally of shelf-carbonate rocks with many intercalations of shale, sediments deposited in a subtidal regime, perhaps at the far edge of a tongue of detritus spreading out from the rising Boothia Uplift to the south. Fossils are locally abundant marine invertebrates, and disarticulated vertebrate remains are also common in places. Scales and spines of acanthodians and thelodonts occur in profusion, with fragments and plates from large and small heterostracans.

Snowblind Bay Formation (Thorsteinsson and Fortier 1954)

This is a coarse limestone breccia and conglomerate unit of apparently northern and northwestern derivation, rather than from the Boothia Uplift. Vertebrates occur in the lower part of the formation.

THE FOSSIL VERTEBRATES

The preservation of skeletal materials depends not only on the death-environment of the animal, but also on many factors operating before burial in sediment takes place. Currents, waves and storms, not to mention the agencies of biological decay and the activities of scavengers, are all especially important where the animal is aquatic. The vertebrates mentioned here had little hard internal skeleton, but possessed extensive bony "armour" or exoskeletal protection, as well as thick bony scales and spines.

The modes of occurrence of these vertebrate fossils range from isolated scales and fragments a few millimetres in size, and in barren coarse clastic matrices, to dense concentrations of fragments and entire head or body armour in finer clastic sediment. Articulated specimens are rare but several instances of relatively complete fossils are known.

(Dineley 1968, 1976). In the carbonate facies, "bone-bed" accumulations of vertebrate debris are common on northern Prince of Wales Island, whereas isolated but numerous well-preserved exoskeletal plates occur in many areas. R. Thorsteinsson (personal communication) has discovered several instances of remarkably complete pteraspid and other carapaces or squamation in the carbonate-facies of this region. Probably the vertebrates were variously distributed between the freshwater, brackish and marine environments. Sudden inundations may have swept non-marine forms from their habitats into the sea, but it also appears that many fish (agnathans, thelodonts and acanthodians) were capable of a marine existence or may have migrated seasonally between sea and fresh water. The numbers of different vertebrate species present at a locality ranges from one to as many as 15; most localities seem to yield about five species, and these are commonly of heterostraci. Additionally there may be one or two species of cephalaspids, plus acanthodian and thelodont scales or spines that are difficult to identify closely.

The marine environments supported a rich benthonic invertebrate fauna, part of a complex ecosystem that may have been highly productive and capable of supporting a variety of vertebrates. The continental environments undoubtedly supported algal and primitive vascular floras with perhaps attendant invertebrates. Some of these environments, especially the lacustrine, may also have been "vertebrate-friendly" habitats. A discussion of the nature of the radiation and dispersal of the agnatha in Late Silurian-Early Devonian times is given elsewhere (Dineley, in press).

Most of the fossils belong within three broad categories, ostracoderms, placoderms, and gnathostomes.

Ostracoderms were jawless forms with extensive exoskeleton about the head and body, and with thick bony scales on the hind parts (Figure 4). Some were dorso-ventrally flattened, others were fusiform (spindle-shaped). In size they range from 3-5 cms to 30 cms or more long. They are probably related to modern lampreys and hagfishes. The Heterostraci were ostracoderms with a head and body armour of several paired plates set around central dorsal and ventral discs (Figure 5). Paired fins are unknown but the tail was stout and used for propulsion. The Osteostraci were ostracoderms possessing a solid cranial skeleton, flattened, and horseshoe-shaped in plan and with ventral mouth and gill-openings and a scaled, laterally compressed body and tail. Most forms had small pectoral fins.

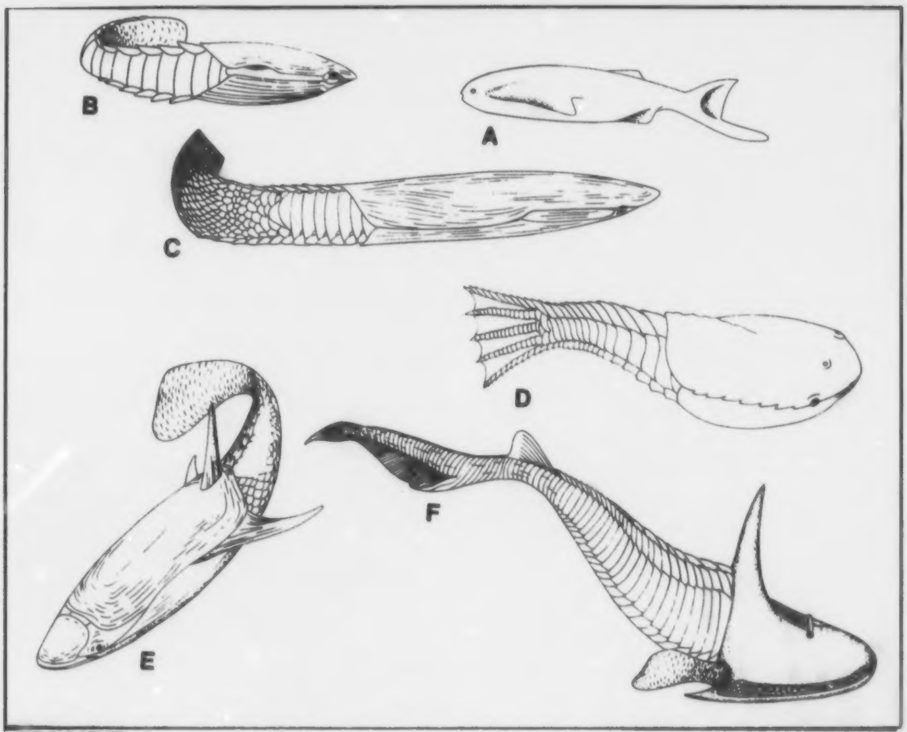


FIGURE 4: Various types of mid-Palaeozoic agnatha (ostracoderms). These forms are among the few that are known from relatively complete skeletons. A. Thelodus, a small form lacking bony plates (length 3-8 cm); B. Anglaspis, with several large plates covering the forepart of the body, and with large bony scales behind (about 8 cm long); C. Torpedaspis, a long narrow agnathan, common in the Peel Sound Formation on Somerset Island (up to 35 cm long); D. Ctenaspis, a short deep-bodied form with a large tail-fin (about 10 cm long); E. A pteraspid, a common form with many genera, some individuals of which reached 30 cm long; F. Machairaspis, a cehalaspid known in Spitsbergen and Arctic Canada (about 30 cm long).

Anaspids were jawless, entirely covered with small lozenge-shaped scales; in place of the normal paired-fins were two long lateral-fins on the lower body. They are known in the Cape Phillips Formation of Cornwallis Island, but await description (Thorsteinsson 1967).

Thelodonts were dorso-ventrally flattened fishes about 5-10 cm long with terminal mouths and a body-covering of tiny stud-like scales. The oldest thelodonts occur in Llandoverian-age rocks on Cornwallis Island, whereas the youngest are from the Peel Sound Formation (Turner and Dixon 1971).

The cephalaspids (Osteostraci) are known from relatively few well-preserved fossils, mostly headshields. The head and gill parts were encased in a solid box of bone, which was dorso-ventrally flattened and somewhat horseshoe-shaped in plan. Behind it the body was rather laterally compressed, triangular in cross-section and covered in longitudinal rows of small elongate scales. The upper surface of the head shows two close-set eyes near the median line with a simple nasal opening and a tiny pineal opening between them. The most conspicuous feature of this surface is the presence of two lateral "fields" and a dorsal "field" covered in tiny bony plates. They are connected to the vestibular part of the ear by several large canals, and seem to have had some form of sensory function. On the flat undersurface of the head is a jawless mouth with pairs of gill-openings at the margin of a subcircular central scale-area. Apparently there were deep paired gills within the head, and water was kept moving through the mouth and gills by a flexible floor - perhaps pulsing up and down. The whole internal anatomy of the head is very like that of the modern hagfish (*Petromyzon*).

Most Canadian cephalaspids were about 15 cm long, but an early form (*Hemicyclaspis*) from Somerset Island was about twice that length. Like many other genera, it had a pair of scaled 'flippers' behind the cornual (lateral) angles of the head shield. Cephalaspids were probably benthonic, but reasonably active swimmers on occasion. The strong tail fin suggests as much.

Rather like the cephalaspids, were the anaspids, which are rare but have been discovered in the Canadian Arctic Islands by R. Thorsteinsson. Anaspids are much the same size as the cephalaspids, but covered in small bony platelets and scales. They were fusiform and rather laterally-compressed fishes having jawless terminal mouths, small eyes and a row

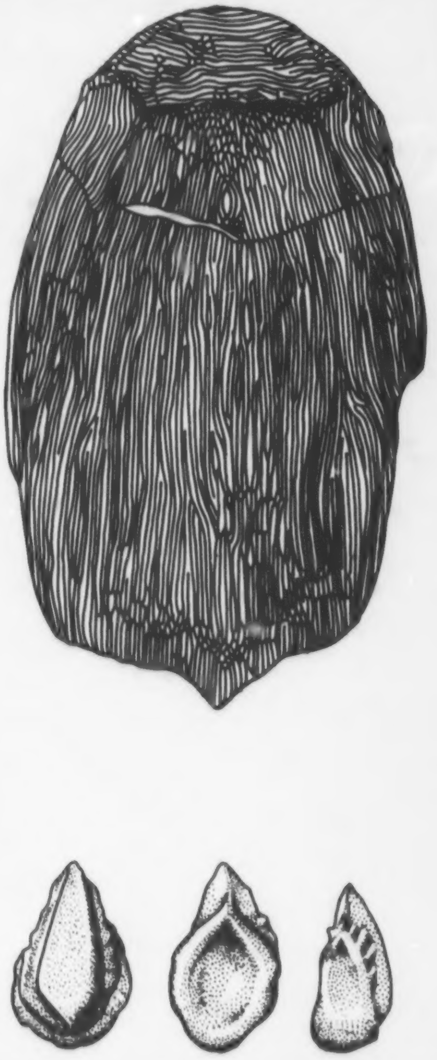


FIGURE 5: Top: The dorsal shield of a typical small cyathaspid (**Archegonaspis**) from the Late Silurian of Somerset Island shows a relatively simple pattern of lines developed on the smooth external surface of the bone. Many cyathaspids have patterns of lines that are diagnostic of the species (after Loeffler and Jones 1976). Bottom: Thelodont denticles; **Logania**, a genus of Late Silurian thelodonts from eastern Prince of Wales Island (after Turner and Dixon 1971). The length of each denticle is between 0.3 mm and 0.5 mm. The animal possessed several thousand such denticles in its skin, the shape of denticle varying with position on the body (Figure 4).

of gill-openings on each side of the head. They seem to have lacked lateral fins but had a strong hypocercal tail. Anaspids were probably active swimmers that have been variously regarded as surface film-feeders or as suctionally grazing the bottom sediment.

The great heterostracan group, the pteraspidomorphs, are very diverse and most abundantly represented in the Arctic Islands. They had a set of well-defined bony plates covering the head and thorax; the hind part of the body and the tail were covered by sets of bony scales, all minutely and distinctly ornamented. Many new forms are known (Elliott 1983, 1984). From the relative simplicity of their armour, the cyathaspids are regarded as the 'basic heterostracans', and they appear earliest in the fossil record.

The cyathaspid head had a few paired plates around central dorsal and ventral median plates, and the body was clad in thick scales. There were no lateral fins. The mouth was at or near the front margin of the head, and the small eyes were on the front lateral margin. Water taken in through the jawless mouth passed through paired gill-chambers and left through openings near the rear of the carapace. The opening of the mouth could be expanded by lowering the array of small oral plates on its lower side. While some species had rather flat underbellies and rested on the bottom, some seem to have lain with flat dorsal sides at the sediment-water interface; others had the torpedo-like bodies of fish that lived amongst fronds of water weed. The more architecturally-complex pteraspids possessed a median dorsal spine, or vane, and cornual spines or planes, which must have been hydrodynamically important. However, the mode of life and activities of these animals remain largely conjectural. The earliest pteraspids seem to have evolved from an advanced group of small cyathaspids, but soon evolved species larger and more varied in shape. They occur in both marine and non-marine sediments (Elliott 1984).

Somewhat earlier to appear in the succession of cyathaspid-like agnatha were the traquairaspids. This group had a most characteristic tubercle-like surface ornamentation on its plates and scales, and in some species there was a smooth central area on the ventral median disc. Some palaeontologists believe that the tubercle ornamentation is a primitive character persisting from earlier forms, each turbercle representing an ancestral scale.

Broad (1973) described three species of the new genus *Boothiaspis* from several horizons in the Canadian Arctic Islands. He believed them to be members of a separate Order, Amphiaspidiformes, previously only known from the northwestern Siberian Platform and southwestern Taimyr (Novitskaya 1971). They have flat dorsal shields, as much as

20 cm in length. The material is, so far, still meagre, and the true affinities of these fossils are not established beyond doubt. Elliott and Dineley (1985) believe that they are cyathaspids.

The Thelodonti, a very poorly known group of small agnathans, have head, trunk and tail regions covered with denticles rather than scales (Figure 6). Complete specimens are extremely rare, but both flattened (skate-like) and rather minnow-shaped body forms are known. In the Canadian biotas the thelodonts are represented by isolated denticles in both marine and non-marine formations.

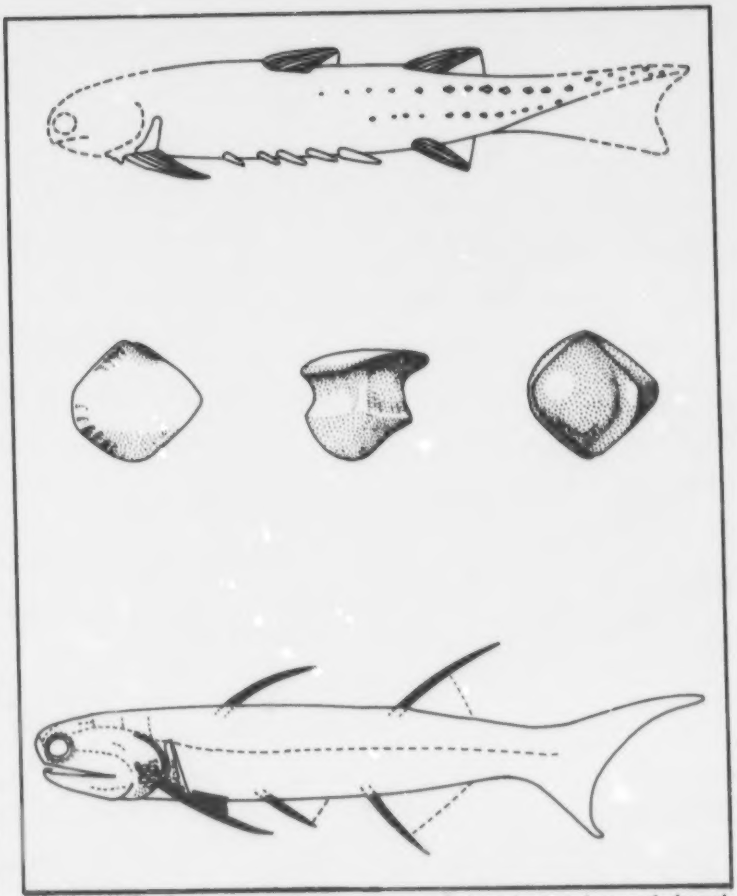


FIGURE 6: Acanthodians are represented by bony spines and dermal denticles (centre). Top: Lupopsyrus, about 4.5 cm long. Bottom: Ischnacanthus, about 10-15 cm long; the denticles range between 0.5 and 1.0 mm in diameter, and formed a dense cover over the entire head and body of the fish.

Representing the major, but rather ill-defined group, the placoderms, are the arthrodires (e.g. *Eskimaspis arctica*, *Baringaspis dineleyi*). They are represented by several species in the Peel Sound Formation. The cranial covering of bony plates articulated with those of the pectoral region, and there were simple but efficient joints. All the exoskeletal plates were clearly ornamente[illegible]y small almost star-shaped tubercles. From each side of the forward part of the body projected bony cornua or spines, which may have assisted in hydrodynamic stability. Small pectoral fins lay immediately behind these projections. The tail tapered rapidly and was covered by thin scales. Arthrodires are never common in these faunas and were probably predators or scavengers (Miles 1973; Dineley and Liu 1984).

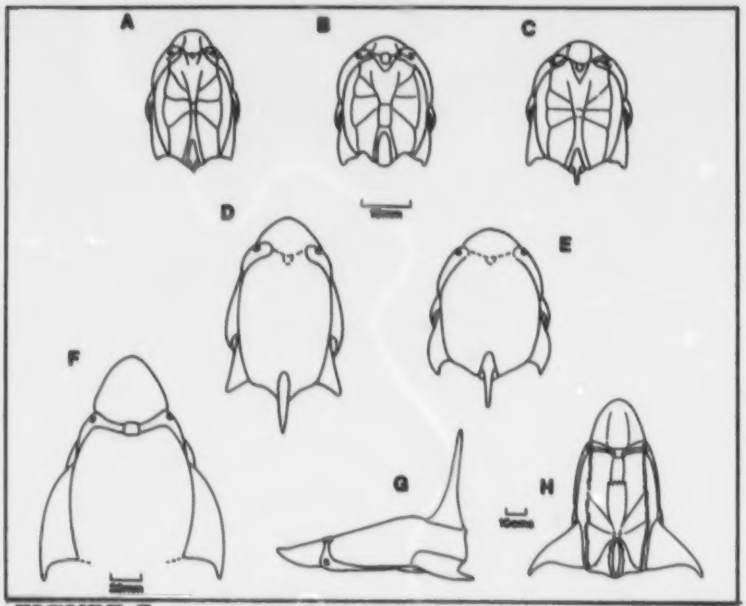


FIGURE 7: Pteraspids show many variations in the architecture of the dorsal shield. A-E are small early forms from the lower member of the Peel Sound Formation: F-H are larger and from the upper member of the same formation. A, B and C show the sensory-canal lines: the orbits that contained the eyes are black. Note size differences indicated by the scale bars A-E, F, and G and H. A. Protopteraspis sartokia, southeastern Prince of Wales Island; B. P. siliktokia, southeastern Prince of Wales Island; C. P. pygmaea, eastern Prince of Wales Island; D. P. (?) arctica, southern Somerset Island; E. P. (?) corniga, northwestern Somerset Island; F. Escharaspis alata, reconstruction of the dorsal shield. Prince of Wales Island, Peel Sound Formation; G. Unarkaspis schultzei, reconstruction of the dorsal shield in side view; H. Reconstruction of the dorsal shield (top view) showing the sensory-canal system. Northern Prince of Wales Island and eastern Cornwallis Island.

Comparatively rare but widespread among the Canadian early vertebrates are the acanthodians, "spiny sharks" - the first true jawed or gnathostome fishes (Figure 7). They were minnow-like, small and active animals with minute square-crowned scales and stout bone spines at the leading edge of dorsal, anal and paired fins, and with an elegant heterocercal tail fin. Acanthodians had an internal skeleton and various small bones in the complex head assemblage. Conspicuously large eyes were set well forward on the blunt head and above the well-developed jaws. Teeth in some species were numerous, sharp, and arose directly from the jaw cartilage: they also occur as centrally-placed whorls of multicusp teeth held to the jaw cartilage by connective tissue. Apparently these jaws belong to rapacious, or at least carnivorous, little fish that were mid- or surface-water feeders. Articulated fossil acanthodians are rare but are known elsewhere in formations of marine character as well as in those (e.g. the Peel Sound Formation) that are probably fluvial in origin.

Occurring with pteraspid and arthrodire remains in the calcareous facies of the Peel Sound Formation is at least one species of large gnathostome fish. It is a member of the porolepid group, probably a large active predator (Bernacsek 1975). The head-covering of bony plates and the scales have innumerable tiny holes or pores in the outer shiny surface - hence the name. A similar if not identical fossil gnathostome, *Powichthys thorsteinssoni*, has been described from the Drake Bay Formation on the west coast of Prince of Wales Island by Jessen (1973). Stout and well-armed with sharp teeth, such fishes were perhaps to be found lurking at the edge of schools of agnatha, or lying in wait for prey amidst weeds of lagoons and watercourses. These are some of the earliest true jawed-fishes known anywhere, though a few fossils of a comparable type have been found in rocks of this relatively early date in Spitsbergen, Europe and China. In later Devonian times they grew to a metre or more in length.

The paleoecology of these vertebrates is poorly understood. There is much scope for work on the swimming and hydrodynamics of the animals, as the head and body shape are well known and some tails have been discovered intact. Feeding habits and general behavioural studies are more difficult to conjecture, but most forms of the Heterostraci seem to have been members of small schools rather than solitary, to judge from the numbers present at certain levels. Some trace fossils (burrows and trails) are known in the sandy strata: invertebrate body fossils occur rarely but giant eurypterids are known. Synecological principles can rarely be suggested as most of the vertebrate assemblages are thanatocoenoses

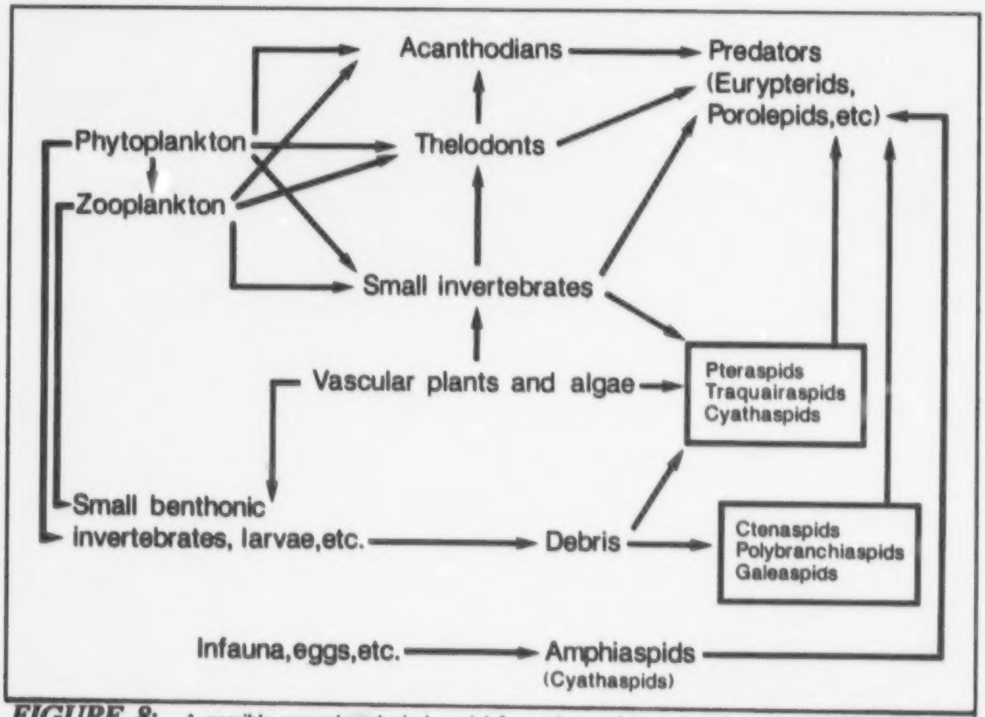

Acanthodians
Predators
(Eurypterids,
Porolepids,etc)
Phytoplankton
Thelodonts
Zooplankton
Small invertebrates
Vascular plants and algae
Pteraspids
Traquairaspids
Cyathaspids
Small benthonic
invertebrates, larvae,etc.
Debris
Ctenaspids
Polybranchiaspids
Galeaspids
Infauna,eggs,etc.
Amphiaspids
(Cyathaspids)

FIGURE 8: A possible general ecological model for early vertebrates, based on agnatha from all of the vertebrate provinces. The amphiaspids seem to be exclusively Siberian, the polybranchiaspids and galeaspids Chinese. The amphiaspids, being blind may have been burrowers. The ctenaspids (and polybranchiaspids and galeaspids in China) may have been active at the bottom sediment-water interface, where conditions tended toward the anoxic. Pteraspids, traquairaspids and most cyathaspids were benthonic or nektonic in habit. Porolepids and other gnathostomes were active nekton as were the thelodonts.

("death assemblages"). I have tentatively suggested an ecosystem model (Dineley 1984) (Figure 8).

The use of early vertebrates in the biostratigraphy of mid-Palaeozoic rocks has advanced recently (Dineley 1984), especially in northern Canada (Thorsteinsson 1980; Elliott 1984). Correlations between this area, Spitsbergen and Europe rest upon a significant number of generic and specific similarities in the vertebrate fauna. There is no doubt that the faunas from these localities all belong to a single palaeobiological province.

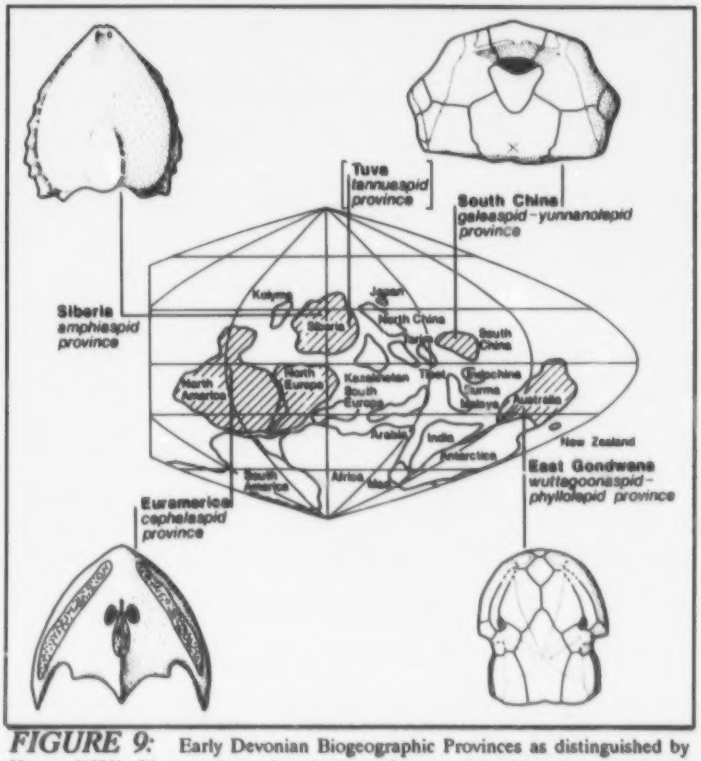

Tuva
tannuaspid province
South China
galeaspid - yunnanolepid province
Siberia
amphiaspid province
Kolyma
Japan
Siberia
North China
Tarim
South China
North America
North Europe
Kazakhstan
South Europe
Tibet
Indochina
Burma
Malaya
Australia
Arabia
India
New Zealand
Antarctica
South America
Africa
Mad.
East Gondwana
wuttagoonaspid - phyllolepid province
Euramerica
cephalaspid province

FIGURE 9: Early Devonian Biogeographic Provinces as distinguished by Young (1981). Illustrated are dorsal views of an amphiaspid and a cephalaspid headshield, the cranial plates of a yunnanolepid antiarch and of a wuttagoonaspid arthrodire. In this reconstruction of world geography Arctic Canada lies somewhat south of the Equator (cf. Figure 10).

EARLY DEVONIAN VERTEBRATE BIOGEOGRAPHY

Young (1981, 1986) has suggested that five biogeographical vertebrate provinces may be distinguished from faunal lists of the Early Devonian: Euramerica, Siberia, Tuva, South China and Eastern Gondwana (Figure 9). The northern four were separated from that of Gondwanaland by a persistent marine barrier. Each northern province is characterized by a distinctive assemblage of Agnatha, whereas the East Gondwana province is recognized by the presence of wuttagoonaspid placoderms. South China perhaps hosted the most distinctive faunas: its agnathans include bizarre forms and others with possible adaptations to almost anaerobic environments. The Siberian (Angara) endemic fauna included several blind agnathans. Relative isolation of these provinces may have been responsible for this endemism, but it faded in importance by the end of Early Devonian time.

The Euramerican Province, typified by the cephalaspids and the Heterostraci mentioned above, is perhaps both the largest and the most studied province. Its early Devonian vertebrates have long been known from the British Isles, other parts of western Europe and Spitsbergen (Blieck 1982). More recently the North American faunas have been investigated, notably by Denison (1963, 1964) and by a group associated with the Universities of Ottawa and Bristol (Dineley 1968, 1976; Elliott 1983, 1984A,B; Loeffler and Jones 1976; Loeffler 1977). Dineley (1967) was able to establish very detailed biostratigraphic vertebrate correlation between Nova Scotia and the British Isles. Elliott (1984A) has been able to demonstrate the correlation of Canadian Arctic Islands early Devonian vertebrates with the successions in Spitsbergen, Podolia (U.S.S.R.) and Britain. The wealth of taxa upon which these correlations are made is shown in Table 2.

Apparently conditions favourable to early vertebrates prevailed throughout almost the entire coastal-waters zone of the (Euramerican Province) Old Red Sandstone Continent. As time progressed these fishes penetrated more and more the inland freshwater systems. Middle Devonian time saw the establishment of considerable lake-systems with abundant fishes, but none are known definitely at an earlier date. Tropical humid climate allowed the extensive development of inland drainage-systems and the growth of an extensive plant basis for vertebrate-topped ecological pyramids.

THE SIGNIFICANCE OF THE CANADIAN ARCTIC MATERIAL

The availability of many new fossils offers data to improve our understanding of the anatomy and functional morphology of poorly-known and extinct groups of primitive vertebrates. Their evolutionary relationships, the structure and habitats of their communities and possible ecological relationships are becoming clearer. Our improved knowledge of their biogeographical and stratigraphical ranges is important in understanding Devonian correlation and the Devonian biosphere. The Canadian Arctic materials can be compared with those from elsewhere around the Old Red Sandstone Continent. Species in common with those of Yukon and of Spitsbergen are now recognized, and the geographical range of individual species along this portion of the continent's edge may soon be known.

TABLE 2: VERTEBRATE ?COMMUNITIES FROM FORMATIONS ON SOMERSET ISLAND MAY INCLUDE THE FORMS IDENTIFIED HERE. THEY ARE BROADLY USEFUL IN CORRELATION WITHIN THE REGION, AND EVEN WITHIN THE ENTIRE EURAMERICAN PROVINCE. AS MOST OF THESE FOSSILS ARE IN TRANSPORTED "DEATH ASSEMBLAGES", IT IS UNCERTAIN THAT THEY REPRESENT NATURAL LIVING ASSOCIATIONS. THE PROCESS OF FOSSILIZATION MAY HAVE BEEN SELECTIVE: ONLY THE MORE HEAVILY SKELETONIZED FORMS MAY BE REPRESENTED. THE DASHED LINES REPRESENT THICKNESSES OF BARREN STRATA BETWEEN THE FOSSILIFEROUS BEDS (BASED ON ELLIOTT 1984).

PRESSURE POINT

Peel Sound Formation	*Rhachiaspis pteriga* *Torpedaspis elongata* *Pionaspis sp.* *Corvaspis sp.* *? Traquairaspis sp.*	
	— — — — — — — — — — — —	
Somerset Island Fm. U. Member	*Torpedaspis elongata* *Pionaspis sp.* *Corvaspis sp.* *? Traquairaspis sp.* *Cephalaspis sp.* Acanthodii *indet.*	
	— — — — — — — — — — — —	
	Ulutitaspis aquilonia *Boothiaspis alata* *Torpedaspis elongata* *Corvaspis arctica* *Hemicyclaspis murchisoni* *? Traquairaspis sp.* Acanthodii *indet.*	
	— — — — — — — — — — — —	— — — — — — — — — — — —
Somerset Island Fm. L. Member	*Ulutitaspis notidana* *Rhachiaspis pteriga* *Boothiaspis alata* *Torpedaspis elongata* *Pionaspis acuticosta* *?Traquairaspis sp.* Ancanthodii *indet.*	*Boothiaspis ovata* *Torpedaspis elongata* *Pionaspis sp.* *? Traquairaspis sp.* Acanthodii *indet.*
		— — — — — — — — — — — —
		Ariaspis ornata *Pionaspis sp.*

WEST CRESWELL

Somerset Island Fm. U. Member	*Rhachiaspis pteriga*
	Corvaspis sp.
	? Traquairaspis sp.
	Protopteraspis comiga
	Protopteraspis sp.
	Corvaspis sp.
	Pionaspis sp.
	? Traquairaspis sp.
	\- - - - - - - - - - - -
	Boothiaspis ovata
	Torpedaspis elongata
	Pionaspis sp.
	Corvaspis sp.
	? Traquairaspis sp.

CAPE ANNE - CUNNINGHAM INLET

Somerset Island Fm. U. Member	*Anchipteraspis crenulata*
	Torpedaspis elongata
	Pionaspis sp.
	Corvaspis sp.
	? Traquairaspis sp.
	Acanthodii *indet.*

So far, several reconstructions of the entire animals have been attempted (Broad and Dineley 1973; Dineley 1968, 1976) and the modes of life of particular forms as largely infaunal or semi-buried have been suggested.

Ecological studies have yet to be made, but data relevant to some localities are now sufficient for them to begin.

Evolutionary relationships have been most successfully postulated in the case of the early pteraspids. Elliott's work (1984A) has shown that the group may be derived from cyathaspid ancestors in earliest Devonian time. However, the origins of the traquairaspids, a group abundantly represented in both Somerset Island and Peel Sound formations, remain obscure. The cyathaspids themselves have been regarded as the simplest group of the heterostracans, originating well before Late Silurian time. Many very small cyathaspid fossils found on Somerset Island at low stratigraphic levels await study. It is clear that the cyathaspids are a more varied group than previously suggested and that fundamental taxonomic revision of the cyathaspids is necessary.

In biogeographical terms the Arctic discoveries confirm the distinctive character of the Euramerican (Cephalaspid) Province. The possible connection with the Angara (Amphiaspid) Province provided by the identification of *Boothiaspis* as an ?amphiaspid has not been supported by further discoveries (Elliott and Dineley 1985). Oceanic deep waters may have been a barrier to the migration of the agnatha from one continent to another at the beginning of the Devonian period. Connections between the Franklinian Arctic Canadian terrain and more distant parts of the Laurussian continent (Western Europe and the U.S.A.) are well established on the basis of faunal lists. Nevertheless, there are striking differences between the faunas of the different areas. For example, there are over 25 different osteostracans known from Spitsbergen, whereas only about five different forms are so far determined from the Canadian Arctic. The Canadian localities yield many species of traquairaspids (not all described), while only three or four are known in Europe. The genus *Protopteraspis* is widespread but its forebears appear to be limited, so far, to the vicinity of Prince of Wales Island. The most complex fauna yet known is from Spitsbergen, where one level yields 30 genera, all but seven being agnatha. Probably the acme of diversity is achieved in the late Lochkovian (=Gedinnian) stage of the Lower Devonian throughout the entire Euramerican Province (Figures 10,11). Decline from this point was fairly rapid.

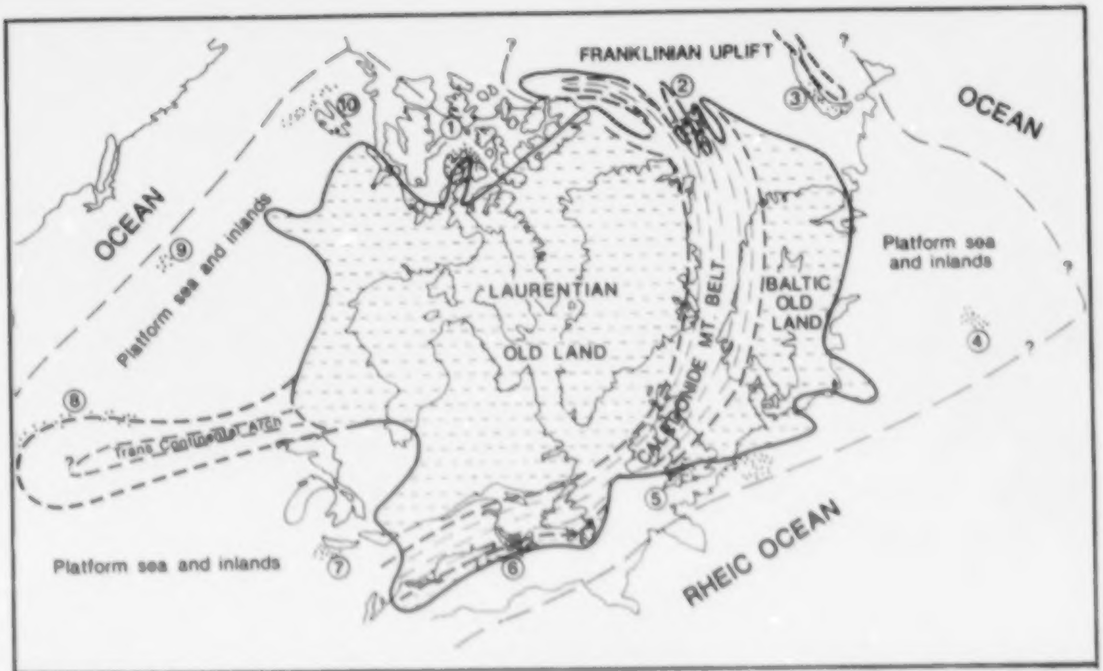

FRANKLINIAN UPLIFT
OCEAN
OCEAN
Platform sea and inlands
Platform sea and inlands
LAURENTIAN
OLD LAND
BALTIC
OLD
LAND
CALEDONIDE MT. BELT
Trans Continental Arch
Platform sea and inlands
RHEIC OCEAN
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
?

FIGURE 10: The Euramerican Vertebrate Province: an oversimplified map of the Old Red Sandstone Continent (Laurussia) and its surrounding waters in early Devonian time, showing the principal regions (stippled) in which vertebrates have been found. Key: (1) Canadian Arctic Islands (District of Franklin); (2) Spitsbergen; (3) Novaya Zemlya (U.S.S.R.); (4) Podolia (U.S.S.R.); (5) Western Europe (British Isles - West Germany); (6) Acadia (Maritime Provinces, Canada); (7) Ohio - New York (U.S.A.); (8) Nevada - Wyoming (U.S.A.); (9) Alberta (Canada); (10) Selwyn - Mackenzie Mountains (Northwest Territories, Canada). The full extent and relief of the Trans Continental Arch is uncertain. The equator lay a little to the south of the European margin of the continent and along the bottom left of the map.

The thelodonts appear to be an exceptional group in that, throughout their history, they were probably capable of a fully marine existence. While they were common in the waters about Laurussia between mid-Silurian and the end of Early Devonian time, they then became extinct there. However, they did survive until Late Devonian time in Australia.

The great majority of ostracoderms died out by the end of the Early Devonian. Nevertheless, in Canada two genera of cephalaspids and two of anaspids are found in the Late Devonian. They occur as 'living fossils' among the Late Devonian gnathostome fishes of the Escuminac Formation in Quebec, where they may have persisted in an intermontane basin refuge. The Franklinian grounds offered no such shelter to local ostracoderms. Halstead (1987) shows that different groups throughout the world died out at slightly different times. What crises brought about the major extinctions, and thereafter the final demise of agnathan groups, remain unknown. Competition from gnathostomes seems to be among the most probably causes.

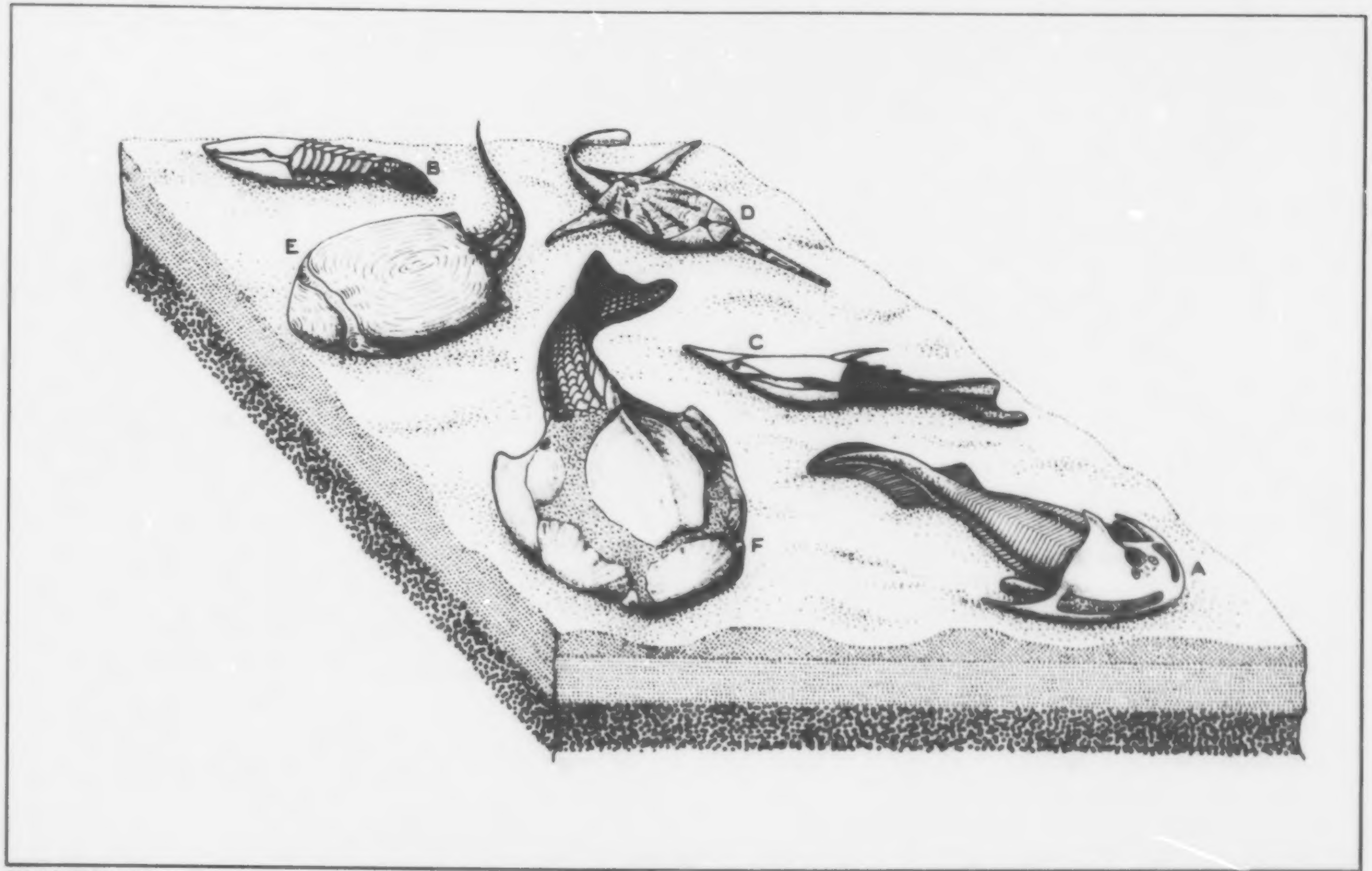


FIGURE 11: Agnathans from various parts of the Euramerica Province (Cephalaspid Province). A. a generalized cephalaspid such as has been found in many parts of the province; B. Anglaspis, a small cyathaspid known in Arctic Canada, Spitsbergen and Europe; C. Pteraspis, a medium-sized pteraspid found in Europe; D. Doryaspis, a bizarre pteraspid known only in Spitsbergen; E. Zascinaspis, a large "blunt-nosed" pteraspid known from Europe (Podolia) and in North America; F. A late psammosteid ostracoderm from Germany found in association with marine invertebrates; in this type of ostracoderm the bony plates were separated from one another by mosaic areas of small platelets. So far no specimens of this kind have yet been found in North America (after Dineley 1984).

ACKNOWLEDGEMENTS

I am indebted to many Canadian colleagues and friends for their kindness and assistance over a very long time. Much of my early work was supported both financially and materially by the Geological Survey of Canada and by the National Museum of Canada. Dr. E.J. Loeffler and Dr. D.K. Elliott, themselves able contributors in this field of study, have generously and helpfully commented on a draft of this paper.

REFERENCES

Bernacsek, G.M. 1975. New Devonian jawed fishes from northern Canada. Unpublished Ph.D. thesis. University of Bristol, Bristol, U.K.

Blieck, A. 1982. Les grandes lignes de la biogéographie des hétérostracés du silurien supérieur - dévonien inférieur dans le domaine nord-Atlantique. Palaeogeography, Palaeoclimatology, Palaeoecology 38:283-316.

Blieck, A., D. Goujet, and P. Janvier. 1987. The vertebrate stratigraphy of the Lower Devonian (Red Bay Group and Wood Bay Formation) of Spitsbergen. Modern Geology 11:197-217.

Broad, D.S. 1973. Amphiaspidiformes (Heterostraci) from the Silurian of the Canadian Arctic Archipelago. Contributions to Canadian Palaeontology. Geological Survey of Canada, Bulletin 222:35-46.

Broad, D.S. and D.L. Dineley. 1973. *Torpedaspis*, a new Upper Silurian and Lower Devonian genus of Cyathaspididae (Ostracodermi) from Arctic Canada. Contributions to Canadian Palaeontology. Geological Survey of Canada, Bulletin 222:53-91.

Broad, D.S., D.L. Dineley, and A.D. Miall. 1968. Peel Sound Formation of Prince of Wales Island and adjacent islands: a preliminary report. Arctic 21:84-91.

Brown, R.L., I. Dalziel, and R.B. Rust. 1969. The structure, metamorphism and development of the Boothia Arch, Arctic Canada. Canadian Journal of Earth Sciences 6:525-543.

Chaloner, W.G. and J.D. Lawson (Editors). 1985. Evolution and environment in the Late Silurian and Early Devonian. Proceedings of a Royal Society discussion meeting (May 2-3, 1984). The Royal Society, London. 342 pp.

Denison, R.H. 1963. New Silurian Heterostraci from southeastern Yukon. Fieldiana, Geology 14:105-141.

Denison, R.H. 1964. The Cyathaspididae: a family of Silurian and Devonian jawless vertebrates. Fieldiana, Geology 13:309-473.

Dineley, D.L. 1967. The Lower Devonian Knoydart faunas. Journal of the Linnean Society of London (Zoology) 47:15-29.

______. 1968. Osteostraci from Somerset Island. Contributions to Canadian Palaeontology Pt.II. Geological Survey of Canada, Bulletin 165:47-63.

______. 1976. New species of *Ctenaspis* (Ostracodermi) from the Devonian of Arctic Canada. In: Athlon: Essays in Palaeontology in Honour of Loris Shano Russell. Edited by: C.S. Churcher. Royal Ontario Museum, Toronto, pp. 26-44.

______. 1984. Devonian vertebrates in biostratigraphy. Proceedings of the Linnean Society of New South Wales 107:185-196.

______. (in press). The radiation and dispersal of Agnatha in early Devonian time. Proceedings of the 2nd International Symposium on the Devonian System. Canadian Society of Petroleum Geologists, Memoir 14.

Dineley, D.L. and Y. Liu. 1984. A new actinolepid arthrodire from the Lower Devonian of Arctic Canada. Palaeontology 27:875-888.

Dineley, D.L. and E.J. Loeffler. 1976. Ostracoderm faunas of the Delorme and associated Siluro-Devonian formation, Northwest Territories, Canada. Special Paper in Palaeontology 18:1-214.

Elliott, D.K. 1983. New Pteraspididae (Agnatha, Heterostraci) from the Lower Devonian of Northwest Territories, Canada. Journal of Vertebrate Palaeontology 21:389-406.

______. 1984A. A new subfamily of the Pteraspididae (Agnatha, Heterostraci) from the Upper Silurian and Lower Devonian of Arctic Canada. Palaeontology 27:169-197.

______. 1984B. Siluro-Devonian fish biostratigraphy of the Canadian Arctic Islands. Proceedings of the Linnean Society of New South Wales 107:197-209.

Elliott, D.K. and D.L. Dineley. 1985. A new heterostracan from the Upper Silurian of Northwest Territories, Canada. Journal of Vertebrate Palaeontology 5:103-110.

Gibling, M.R. 1978. Sedimentation of the Siluro-Devonian clastic wedge of Somerset Island, Arctic Canada. Unpublished Ph.D. thesis, University of Ottawa, Ottawa, Ontario.

Gibling, M.R. and G.M. Narbonne. 1977. Siluro-Devonian sedimentation on Somerset and Cornwallis islands. Bulletin of Canadian Petroleum Geology 25:1145-1156.

Halstead, L.B. 1987. Agnathan extinctions in the Devonian. Memoire Société géologique France (N.S.), No. 150:7-11.

Jessen, H. 1973. A new choanate fish *Powichthys thorsteinssoni* n.g., n.sp., from the early Lower Devonian of the Canadian Arctic Archipelago. Colloques Internationaux du C.N.R.S. 218:212-222.

Jones, B. and O.A. Dixon. 1975. The Leopold Formation: an upper Silurian intertidal/supratidal carbonate succession on northeastern Somerset Island, Arctic Canada. Canadian Journal of Earth Sciences 12:395-411.

______. 1977. Stratigraphy and sedimentology of Upper Silurian rocks, northern Somerset Island. Canadian Journal of Earth Sciences 14:1427-1452.

Kerr, J.W. 1975. Cape Storm Formation - a new Silurian unit in the Canadian Arctic. Bulletin of Canadian Petroleum Geology 23:67-83.

______. 1977. Cornwallis Fold Belt and the mechanism of basement uplift. Canadian Journal of Earth Sciences 14:1374-1401.

Kerr, J.W. and C.D.S. De Vries. 1976. Structural geology of Somerset Island. Geological Survey of Canada, Paper 76-1A:493-495.

Loeffler, E.J. 1977. Additional late Silurian ostracoderms from the Leopold Formation of Somerset Island, Northwest Territories, Canada. Palaeontology 20:661-674.

Loeffler, E.J. and B. Jones. 1976. An ostracoderm fauna from the Leopold Formation (Silurian to Devonian) of Somerset Island, Northwest Territories, Canada. Palaeontology 19:757-766.

Miall, A.D. 1970A. Continental marine transition in the Devonian of Prince of Wales Island, Northwest Territories. Canadian Journal of Earth Sciences 7:125-144.

______. 1970B. Devonian alluvial fans, Prince of Wales Island, Arctic Canada. Journal of Sedimentary Petrology 40:556-571.

Miall, A.D., J.W. Kerr, and M.R. Gibling. 1978. The Somerset Island Formation: an Upper Silurian to ?Lower Devonian intertidal/supratidal succession, Boothia Uplift, Arctic Canada. Canadian Journal of Earth Sciences 15:81-89.

Miles, R.S. 1973. An actinolepid arthrodire from the Lower Devonian Peel Sound Formation,, Prince of Wales Island. Palaeontographica Abt. A., 143:109-118.

Muir, I.D. and R.B. Rust. 1982. Sedimentology of a Lower Devonian coastal alluvial fan complex: the Snowblind Bay Formation of Cornwallis Island, Northwest Territories, Canada. Bulletin of Canadian Petroleum Geology 30:245-263.

Narbonne, G.M. and O.A. Dixon. 1982. Physical correlation and depositional environments of Upper Silurian rubbly limestone facies in the Canadian Arctic Islands. In: Arctic Geology and Geophysics: Proceedings of the 3rd International Symposium on Arctic Geology. Edited by: A.F. Embry and H.R. Balkwill. Canadian Society of Petroleum Geologists, Memoir 8:135-146.

Novitskaya, L. 1971. Les amphiaspides (Heterostraci) du Dévonien de la Sibérie. Cahiers de Paléontologie C.N.R.S. 130 pp.

Ormiston, A.R. 1969. A new Lower Devonian rock unit in the Canadian Arctic Islands. Canadian Journal of Earth Sciences 6:1106-1111.

Thorsteinsson, R. 1958. Cornwallis and Little Cornwallis islands, District of Franklin, Northwest Territories. Geological Survey of Canada, Memoir 294:1-134.

______. 1963. Prince Alfred Bay, Devon Island. Geological Survey of Canada, Memoir 320:221-222.

______. 1967. Preliminary note on Silurian and Devonian ostracoderms from Cornwallis and Somerset islands, Canadian Arctic Archipelago. Problèmes actuels de Paléontologie C.N.R.S. 218:45-47.

______. 1980. Stratigraphy and conodonts of Upper Silurian and Lower Devonian rocks in the environs of the Boothia Uplift, Canadian Arctic Archipelago. Contributions to Stratigraphy, Pt.1. Geological Survey of Canada, Bulletin 292:1-38.

Thorsteinsson, R. and Y. Fortier. 1954. Report of progress on the geology of Cornwallis Island, Arctic Archipelago, Northwest Territories. Geological Survey of Canada Paper 53-24:1-25.

Thorsteinsson, R. and E.T. Tozer. 1963. Geology of northern Prince of Wales Island and northwest Somerset Island. Geological Survey of Canada. Memoir 320:221-232.

______. 1970. Geology of the Arctic Archipelago. In: Geology and Economic Minerals of Canada. Fifth Edition. Edited by: R.J.W. Douglas. Geological Survey of Canada, Economic Geology Series 1. pp. 547-590.

Turner, S. and J. Dixon. 1971. Lower Silurian thelodonts from Prince of Wales Island, Northwest Territories. Lethaia 4:385-392.

Young, G.C. 1981. Biogeography of Devonian vertebrates. Alcheringa 15:225-243.

______. 1986. Cladistic methods in Palaeozoic continental reconstruction. Journal of Geology 94:523-537.

MESOZOIC VERTEBRATES OF ARCTIC CANADA

Dale A. Russell[1]

Abstract: The oldest remains of Mesozoic vertebrates in Arctic Canada belonged to primitive ichthyosaurs. The single record of a late Triassic terrestrial reptile is based on a trilophosaur vertebra, formerly believed to be dinosaurian. Ichthyosaur and plesiosaur remains are broadly distributed across the Sverdrup Basin in sediments of middle and late Jurassic age, representing taxa closely allied to contemporaneous forms in Europe and midcontinental North America. During late Cretaceous time, marine fishes, reptiles and birds known from the midcontinent frequented the borders of the opening Arctic Ocean Basin in surprising abundance and diversity. Although remains of land-dwelling dinosaurs have recently been discovered in Alaska in close proximity to the paleopole, so far only a single dinosaur (hadrosaur) bone has been found in the Canadian Arctic Islands. This specimen, from Bylot Island, is currently the world's most northerly record of dinosaur bone.

During Mesozoic time both marine and continental vertebrates inhabiting the boreal region were similar to some forms in mid-latitudes, suggesting that both regions were integrated into a single subplanetary ecosystem dominated by seasonal changes in temperature and daylength.

Résumé: Les vestiges les plus anciens de vertébrés du Mésozoïque dans l'Arctique canadien appartiennent aux ichthyosaures primitifs. La seule occurrence de reptile terrestre datant du Triassique supérieur s'appuie sur une vertèbre de trilophosaure, que l'on croyait autrefois provenir d'un dinosaure. Des restes d'ichthyosaure et de plésiosaure sont largement répandus dans le bassin de Sverdrup, dans des sédiments datant du Jurassique moyen et supérieur, représentant des taxons très proches des formes contemporaines rencontrées en Europe et dans le centre de l'Amérique du Nord. Pendant le Crétacé supérieur, des poissons de mer, reptiles et oiseaux appartenant au centre du continent se retrouvaient sur les bords du bassin de l'océan Arctique en diversité et quantité surprenantes. Bien que des restes de dinosaures terrestres aient été récemment découverts en Alaska, tout près du paléo-pôle, un seul os de dinosaure (hadrosaure) qui a été découvert dans les îles de l'Arctique canadien jusqu'à maintenant. Provenant de l'île Bylot, ce spécimen est présentement l'os de dinosaure le plus septentrional du monde.

Durant l'époque du Mésozoïque, les vertébrés des mers et des continents qui habitaient les régions boréales ressemblaient à quelques formes retrouvées aux latitudes moyennes, ce qui laisse penser qu'un vaste écosystème dominé par des changements saisonniers de température et de durée d'éclairement, englobait les deux régions.

INTRODUCTION

To one accustomed to preservation conditions in lower latitudes, Mesozoic sediments in the Canadian Arctic seem rather poorly consolidated, and plant remains appear to be somewhat more abundantly preserved within non-marine strata. Although Mesozoic sediments are exceptionally well-exposed, vertebrate fossils have never been found in abundance within them. All of the fossil vertebrate occurrences in the Queen Elizabeth Islands known to the author are summarized here, as well as those from nearby regions. Supporting references are minimal in number, and the citations they contain should be examined for information on the vertebrate localities. Balkwill *et al.* (1983) provide an excellent regional stratigraphic overview.

---

[1] Paleobiology Division, National Museum of Natural Sciences, Ottawa, Ontario K1P 6P4

TRIASSIC OCCURRENCES

The first remains of Mesozoic fossil vertebrates to be recovered from the Arctic Islands (and Canada) were collected as a result of the Belcher Search Expedition's efforts to learn the fate of the lost Franklin Expedition. In 1852, on tiny Exmouth Island in Belcher Channel, ichthyosaur vertebrae (Owen 1855; Figure 1) were collected from sediments of middle Triassic age (Anisian-Karnian, Schei Point Formation; Tozer 1961, p. 15, Figure 4; Balkwill 1983; Tozer 1984, p. 41). Vertebrate fossils subsequently collected from this locality by Tozer include *Acrodus* teeth (NMC 9947, identified by W. Langston), a pavement-toothed elasmobranch (shark) also known to occur in Triassic sediments on Spitsbergen, and in Triassic and younger sediments in Europe (Cappetta 1987). Some ichthyosaur vertebrae have been assigned to *Mixosaurus*, a primitive, very widely distributed form also known from Alaska, China, Italy, ?Nevada, Spitsbergen, Switzerland and Timor (McGowan 1978). Articulated ichthyosaur skeletal material has been reported in the Schei Point Formation on Ellesmere Island by A.F. Embry (personal communication, 1988).

A second vertebrate locality was discovered by the Belcher Expedition in 1853 on Cameron Island, at the northwestern end of the Bathurst Group. The specimen consists of a single cervical vertebra (*Arctosaurus*), once thought to be dinosaurian but more recently considered to have belonged to a trilophosaur (D. Baird in Russell 1984, p. 9). It was probably derived from continental sediments of late Triassic age (?Heiberg Formation, personal communication, E.T. Tozer 1988; for locality see Tozer 1963, p. 645). Over 20 years after the recovery of the Cameron Island trilophosaur (Figure 2), the remains of Mesozoic vertebrates were discovered in southern Canada (Russell, L.S. 1966, p. 5).

In 1985, S.R. Ash discovered vertebrae, probably belonging to a small ichthyosaur, and ribs of a larger animal in the Blaa Mountain Formation on western Ellesmere Island. The unit is of middle to late Triassic age (Anisian to Karnian, cf. Balkwill 1983, p. 13).

Vertebrates of middle to late Triassic age from Alaska include paleoniscoid and coelacanth fishes, and *Mixosaurus* (Davies 1987; McGowan 1978). What little is known of Triassic vertebrates from Arctic Canada suggests that they were broadly distributed around the globe. There is nothing in either their taxonomy or their morphology that is inconsistent with the inference drawn by Balkwill *et al.* (1983), on the basis of fluviatile

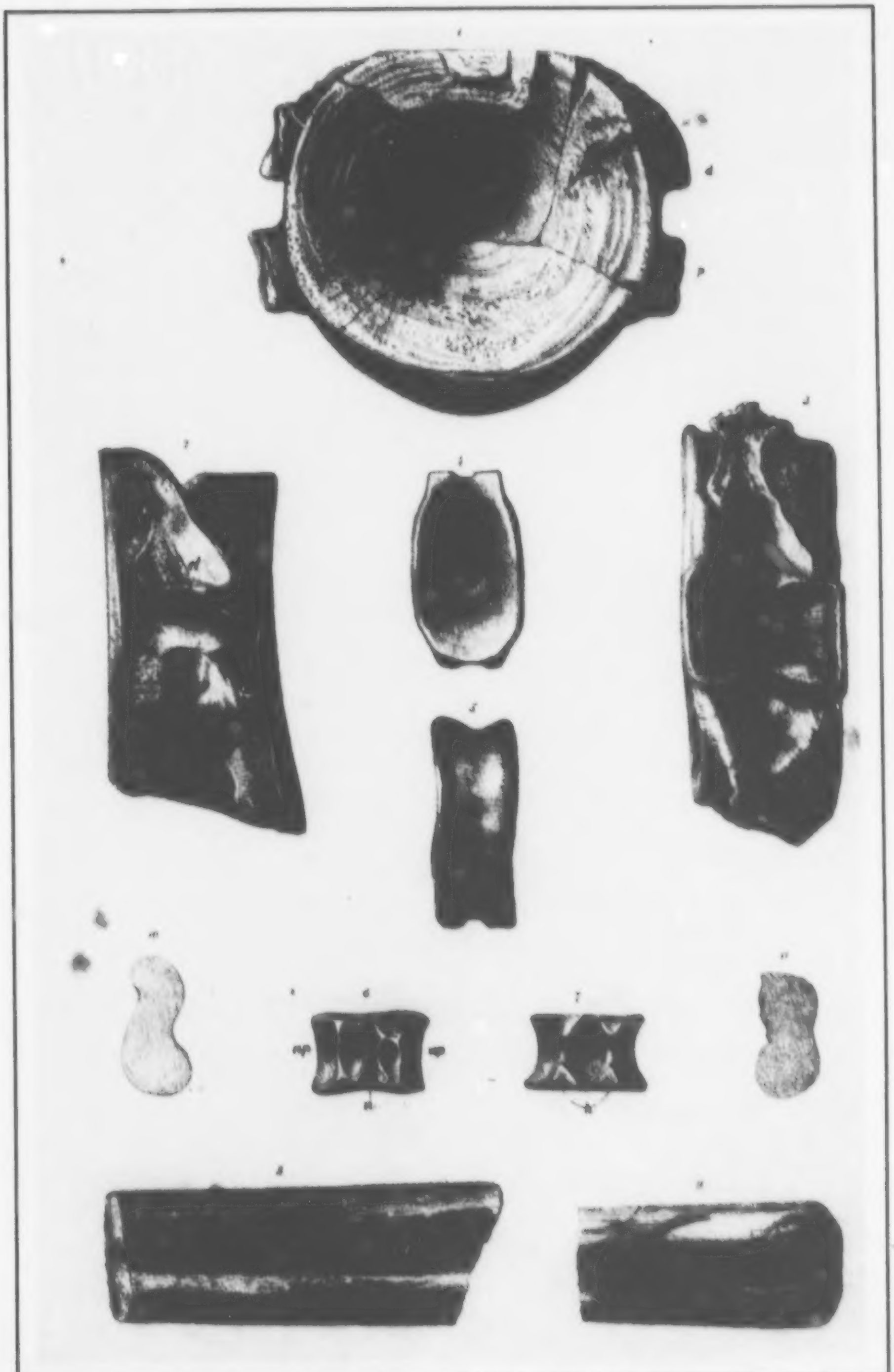


FIGURE 1: Remains of ichthyosaur vertebrae and ribs from Exmouth Island (between Cornwall and Devon islands) submitted to Professor Richard Owen by Captain Sir Edward Belcher (Owen 1855). These were the first remains of Mesozoic fossil vertebrates recovered from the Arctic Islands and Canada.

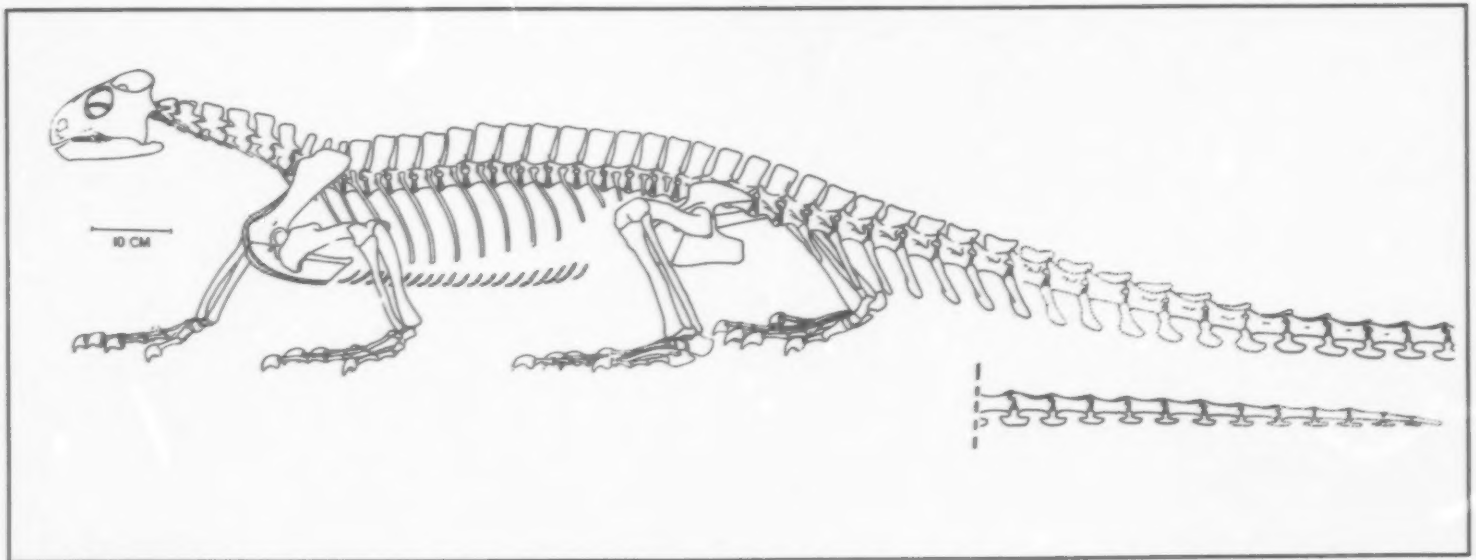


FIGURE 2: A skeletal reconstruction of the medium-sized reptile Trilophosaurus buettneri Case in a walking pose (Gregory 1945). A neck vertebra of a trilophosaur (Arctosaurus) of possible late Triassic age was collected from Cameron Island in 1853. (Posterior tail vertebrae were cropped and inset below to give a clearer idea of the length of the animal).

red-beds and marine limestones, that the regional climate was hot and seasonally arid during middle and late Triassic time.

JURASSIC OCCURRENCES

All of the Jurassic vertebrate records cited here represent marine animals collected from sediments of middle to late Jurassic (Bajocian to Volgian) age. Except where noted, the occurrences are listed in Russell (in press, B). Ichthyosaur fossils are relatively common, and have been found on Axel Heiberg, Cameron (Tozer 1963, p. 645), Ellef Ringnes, Mackenzie King, Melville and Prince Patrick islands. The genus *Ophthalmosaurus* has been identified on several of these islands, and is also known to occur in Argentina, England, France and the western United States (McGowan 1978, 1983, p. 165). An associated skeleton found on Melville Island belonged to a specimen estimated to have been 6.5 m long. Near this specimen both topographically and stratigraphically, was the skeleton of a cryptoclidid plesiosaur, which closely resembles contemporary specimens described from Spitsbergen and England. Another Jurassic plesiosaur occurrence has been documented on the North Slope of Alaska (Davies 1987).

EARLY CRETACEOUS OCCURRENCES

Only a few vertebrate specimens of this age are known from Arctic Canada. Plesiosaur material has been identified from marine strata (Christopher Formation, of Aptian-Albian age; Balkwill 1983) deposited on Melville and Mackenzie King islands. This has been identified by W. Langston (Tozer and Thorsteinsson 1964, pp. 159, 162), respectively, as elasmosaurid and polycotylid.

Early Cretaceous dinosaur footprints (iguanodont and carnosaur) have long been known to occur on Spitsbergen (Edwards *et al.* 1978). Sediments of the same age and lithology on Axel Heiberg Island (Isachsen Formation, personal communication, A.F. Embry, 1988; Valanginian to Barremian,Balkwill 1983) were examined in the course of The Dinosaur Project (China, Canada, Alberta) during the summer of 1986, but no footprints or any other vertebrate fossils were discovered. Footprints of small theropod and ornithopod dinosaurs and birds, as well as dinosaur skin impressions, are known to occur in slightly younger sediments (Albian-Cenomanian) on the North Slope of Alaska (Davies 1987). An Alaskan turtle specimen may be of paleogeographic interest in that it apparently shows resemblances to early Cretaceous terrestrial turtles from Asia (Parrish *et al.* 1987).

LATE CRETACEOUS OCCURRENCES

Remains of marine vertebrates are relatively common in late Cretaceous (Santonian to Maestrichtian) sediments (Smoking Hills and Mason River formations, and equivalent strata) near the Beaufort Sea coast in the District of Mackenzie, and on Banks and Eglinton islands. A diverse fauna of fishes (including acipenserids, crossognathids, ichthyodectids, cimolichthyids, pachyrhizodontids, enchodontids, dercetids), plesiosaurs (elasmosaurids and cimoliasaurids), mosasaurs and toothed birds (hesperornithiforms) has been identified in these strata. The same fauna probably also occurs on northern Banks, Amund Ringnes, Ellef Ringnes and Ellesmere islands, where strata of similar age (Kanguk Formation, Cenomanian through Campanian) have yielded material belonging to ichthyodectid, osmeroidid, salmoniform and enchodontid fishes and undetermined plesiosaurs (Russell, in press A, and references cited therein). Shark teeth and hesperornithiform bones are also known to occur in contemporaneously deposited strata on the North Slope of Alaska (Davies 1987).

All of these marine vertebrates are known to occur in low-latitude seas (Russell, in press A), indicating that high-level predators in both regions were integrated into a single ecological unit of hemispheric proportions. It is reasonable to suppose that seasonal changes in temperature and daylength produced north-south migrations in these predators. They, however, represent but a fraction of the total diversity of marine vertebrates inhabiting low-latitude seas. It is interesting to note that, at least during early Cretaceous time, boreal marine-invertebrate assemblages were characterized by a lack of diversity and taxonomic separation from their low-latitude counterparts (Balkwill *et al.* 1983, p. 26; Jeletzky 1984). Marine vertebrates may have been less sedentary.

Remains of late Cretaceous (Campanian-Maestrichtian) dinosaurs have recently been described from the North Slope of Alaska, and discussed in the context of theories of dinosaurian extinction (Brouwers *et al.* 1987; Davies 1987; Parrish *et al.* 1987). So far teeth and bones belonging to troodontids (small, large-brained carnivorous dinosaurs), tyrannosaurids, hadrosaurine and possibly lambeosaurine hadrosaurs (personal communication, J.R. Horner, 1988) and ceratopsids have been identified. Dinosaurian diversity seems high in view of the currently small sample-sizes, and, on the basis of similarities in the Asian and North American record in lower latitudes, perhaps at least protoceratopsid and ankylosaurid remains will one day be found on the late Cretaceous Alaskan land bridge between the two continents.

As in the case of contemporary high-latitude marine vertebrates, no indigenous element is, so far, evident in the Alaskan dinosaur assemblage. It is difficult to imagine a geographic situation more conducive to north-south seasonal migration in terrestrial vertebrates than the north-south orientation of the narrow Cordilleran region of North America during Cretaceous time (cf. Zeigler *et al.* 1985, Figure 6). Although many subadult hadrosaur specimens have been recovered from an Alaskan bone-bed (Davies 1987), none belongs to infantile specimens such as have been collected far to the south in Montana (Horner 1984). It is tempting to speculate that some hadrosaurs nested in mid-latitudes, and brought their young north with the flush of high-latitude vegetation in the spring. It is doubtful that all of the Alaskan dinosaurs remained at paleolatitudes of 70-85° throughout the year. Winter darkness was a certainty, and paleobotanical evidence suggests that frosts probably occurred as well (Galbreath *et al.* 1988, Wolfe and Upchurch 1988).

FIGURE 3: Dale Russell proudly displays the first dinosaur bone (an upper hindfoot bone of a juvenile hadrosaur) from the Canadian Arctic Islands.

The metatarsal of a juvenile hadrosaur has recently been collected from terminal Cretaceous (Maestrichtian) sediments on Bylot Island, near northern Baffin Island (Figure 3). Joshua Enookalook, a member of Elliot Burden's field party (Memorial University of Newfoundland) found the specimen in July 1987. The locality lay slightly south of the Alaskan North Slope localities during Cretaceous time (it is north of them now), at a paleolatitude comparable to those of ceratopsian and hadrosaur sites in the District of Mackenzie and the Yukon Territory (Russell 1984). Local climates may have been further ameliorated by the nearby presence of a Cretaceous Gulf Stream (Wolfe and Upchurch 1987, p. 47). Teeth of a mitsukurinid shark (*Scapanorhynchus*) and mosasaur vertebrae have also been recovered from marine sediments of approximately the same age on Bylot Island.

REFERENCES

Balkwill, H.R. 1983. Geology of Amund Ringnes, Cornwall, and Haig-Thomas islands, District of Franklin. Geological Survey of Canada, Memoir 390.

Balkwill, H.R., D.G. Crook, R.L. Detterman, A.F. Embry, E. Hakansson, A.D. Miall, T.P. Poulton, and F.G. Young. 1983. Arctic North America and northern Greenland. In: The Phanerozoic Geology of the World, II The Mesozoic B. Elsevier Science Publishers, The Netherlands. pp. 1-31.

Brouwers, E.M., W.A. Clemens, R.A. Spicer, J.A. Ager, L.D. Carter and W.V. Sliter. 1987. Dinosaurs on the North Slope, Alaska: high latitude, latest Cretaceous environments. Science 237:1608-1610.

Cappetta, H. 1987. Chondrichthyes II, Mesozoic and Cenozoic Elasmobranchii. Handbook of Paleoichthyology 3B. Gustav Fischer Verlag, Stuttgart.

Davies, K.L. 1987. Duck-bill dinosaurs (Hadrosauridae, Ornithischia) from the North Slope of Alaska. Journal of Paleontology 61:198-200.

Edwards, M.B., R. Edwards, and E.H. Colbert. 1978. Carnosaurian footprints in the Lower Cretaceous of eastern Spitsbergen. Journal of Paleontology 52:940-941.

Galbreath, G.J., J.A. Wolfe, E.M. Brouwers, R.A. Spicer, and W.A. Clemens. 1988. Arctic dinosaurs and terminal Cretaceous extinctions. Science 239:10-11.

Gregory, J.T. 1945. Osteology and relationships of *Trilophosaurus*. University of Texas Publication 4401:273-359.

Horner, J.R. 1984. The nesting behavior of dinosaurs. Scientific American 250:130-137.

Jeletzky, J.A. 1984. Jurassic-Cretaceous boundary beds of western and Arctic Canada and the problem of the Tithonian-Berriasian stages in the Boreal Realm. Geological Association of Canada, Special Paper 27:175-255.

McGowan, C. 1978. Further evidence for the wide geographical distribution of ichthyosaur taxa (Reptilia: Ichthyosauria). Journal of Paleontology 52:1155-1162.

______. 1983. The successful dragons, a natural history of extinct reptiles. Samuel Stevens, Toronto and Sarasota.

Owen, R. 1855. Note on some remains of an *Ichthyosaurus* discovered by Captain Sir Edward Belcher, C.B., R.N., at Exmouth Island, in lat. 77°N., long. 96°W. In: E. Belcher - The Last of the Arctic Voyages ... Volume II. Lovell Reeve, London. pp. 389-391.

Parrish, J.M., J.T. Parrish, J.H. Hutchison, and R.A. Spicer. 1987. Late Cretaceous vertebrate fossils from the North Slope of Alaska and implications for dinosaur ecology. Palaios 2:377-389.

Russell, D.A. 1984. A check list of the families and genera of North American dinosaurs. Syllogeus 53:1-35.

______. (in press A). A check list of North American marine Cretaceous vertebrates, including fresh water fishes. Tyrrell Museum of Palaeontology, Occasional Papers 6.

______. (in press B). Jurassic marine reptiles from Cape Grassy, Melville Island. Geological Survey of Canada, Paper.

Russell, L.S. 1966. Dinosaur hunting in western Canada. Royal Ontario Museum, Life Sciences Contribution 70.

Tozer, E.T. 1961. Triassic stratigraphy and faunas, Queen Elizabeth Islands, Arctic Archipelago, Geological Survey of Canada, Memoir 316.

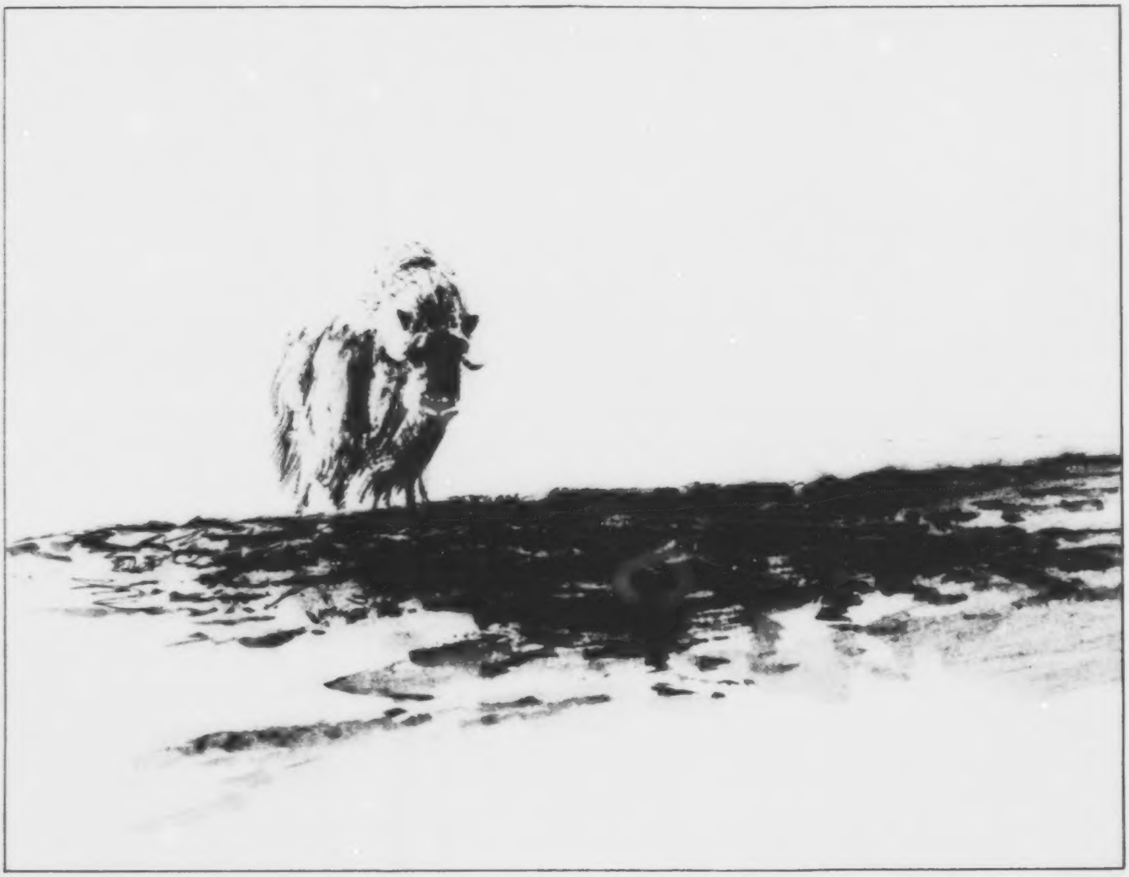
______. 1963. Northwestern Cameron Island. In: Y.O. Fortier *et al.* - Geology of the north-central part of the Arctic Archipelago, Northwest Territories (Operation Franklin). Geological Survey of Canada, Memoir 320:639-645.

______. 1984. The Trias and its ammonoids: the evolution of a time scale. Geological Survey of Canada, Miscellaneous Report 35.

Tozer, E.T. and R. Thorsteinsson. 1964. Western Queen Elizabeth Islands, Arctic Archipelago. Geological Survey of Canada, Memoir 332.

Wolfe, J.A. and G.R. Upchurch. 1987. North American climates and vegetation during the late Cretaceous. Palaeogeography, Palaeoclimatology, Palaeoecology 61:33-77.

Ziegler, A.M., D.B. Rowley, A.L. Lottes, D.L. Sahagian, M.L. Hulver, and T.C. Gierlowski. 1985. Paleogeographic interpretation: with an example from the mid-Cretaceous. Annual Review of Earth and Planetary Sciences 13:385-425.



Illustrated by Brenda Carter

TERRESTRIAL VERTEBRATES FROM THE TERTIARY OF CANADA'S ARCTIC ISLANDS

Mary R. Dawson[1]

Abstract: The only known Arctic terrestrial vertebrates of Tertiary age come from Ellesmere, Axel Heiberg, and Devon islands. Two ages are represented, early Eocene and early Miocene.

The Eocene faunas are most closely allied to others from North America, but also have strong affinities with Europe and some similarities to Asia. The known fauna inhabited delta plains and river margins in coastal areas. Representatives of 29 families, including bony fishes, amphibians, reptiles, birds, and mammals are known; best represented are turtles, crocodilians, and, among the mammals, dermopterans, pantodonts, and perissodactyls. Some members of the Eocene fauna, especially the tortoise, varanid lizard, crocodilian, primates, and dermopterans, suggest (as do associated plant remains) that their habitat included a warm-temperate climate. A polar light-regime, with dark winters and light summers, also prevailed. These environmental conditions may have served both as a limiting factor to the kinds of animals in the fauna, as well as a stimulus to produce specific adaptations to these conditions.

The Miocene fauna is from a peculiarly restricted site: lake-sediments preserved in a meteorite impact-crater. Floral remains suggest cool-temperate, probably coastal, climatic conditions. The fauna, consisting of two taxa of fishes, a swan, and four taxa of mammals, shows both North American affinities (heterosoricine shrew and primitive leporid) and endemism (rhinocerotid and artiodactyl).

Résumé: Les seuls vertébrés terrestres arctiques datant de l'époque tertiaire que l'on connaisse proviennent des îles Ellesmere, Axel Heiberg et Devon. Deux époques, l'Éocène inférieur et le Miocène inférieur, y sont représentées.

Les faunes de l'Écoène, qui s'apparentent étroitement à d'autres provenant de l'Amérique du Nord, ont également de profondes affinités avec celles de l'Europe et quelque similarité avec celles de l'Asie. La faune connue habitait dans les deltas et au bord des rivières dans les régions côtières. Des représentants de 29 familles sont connus et comprennent des poissons osseux, des batraciens, des reptiles, des oiseaux et des mammifères; les mieux représentés sont les tortues et les crocodiliens et, parmi les mammifères, les dermoptères, les pantodontes et les périssodactyles. Quelques membres de la faune de l'Éocène, particulièrement la tortue, le lézard varanidé, les crocodiliens, les primates et les dermoptères permettent de supposer (tout comme les restes de plantes qui les accompagnent) que leur habitat comprenait un climat tempéré chaud, de même qu'un régime d'éclairement polaire, fait d'hivers sombres et d'étés clairs. Ces conditions environnementales peuvent avoir servi soit de facteur limitant pour les animaux de la faune, soit de stimulus vers des adaptations spécifiques à ces conditions.

INTRODUCTION

Fossiliferous non-marine rocks of Tertiary age, the interval between about 65 and 2 million years ago, are present in a number of areas around the Arctic. Characteristically, these rocks contain a good record of fossil plants, but until 1975 none had yielded a record of contemporary land vertebrates. Now however, Canada's Arctic Islands have the unique distinction of providing the only known evidence of land animals that lived at high latitudes during two time intervals in the Tertiary. These two windows on the past, one in the early Eocene between about 50 and 55 million years ago, and the other in the early Miocene about 23 million years ago, are provided by deposits on Ellesmere, Axel Heiberg, and Devon islands (Figure 1). Although Arctic faunal history is woefully incomplete, these

---

[1] Section of Vertebrate Paleontology, Carnegie Museum of Natural History, Pittsburgh, Pennsylvania 15213, U.S.A.

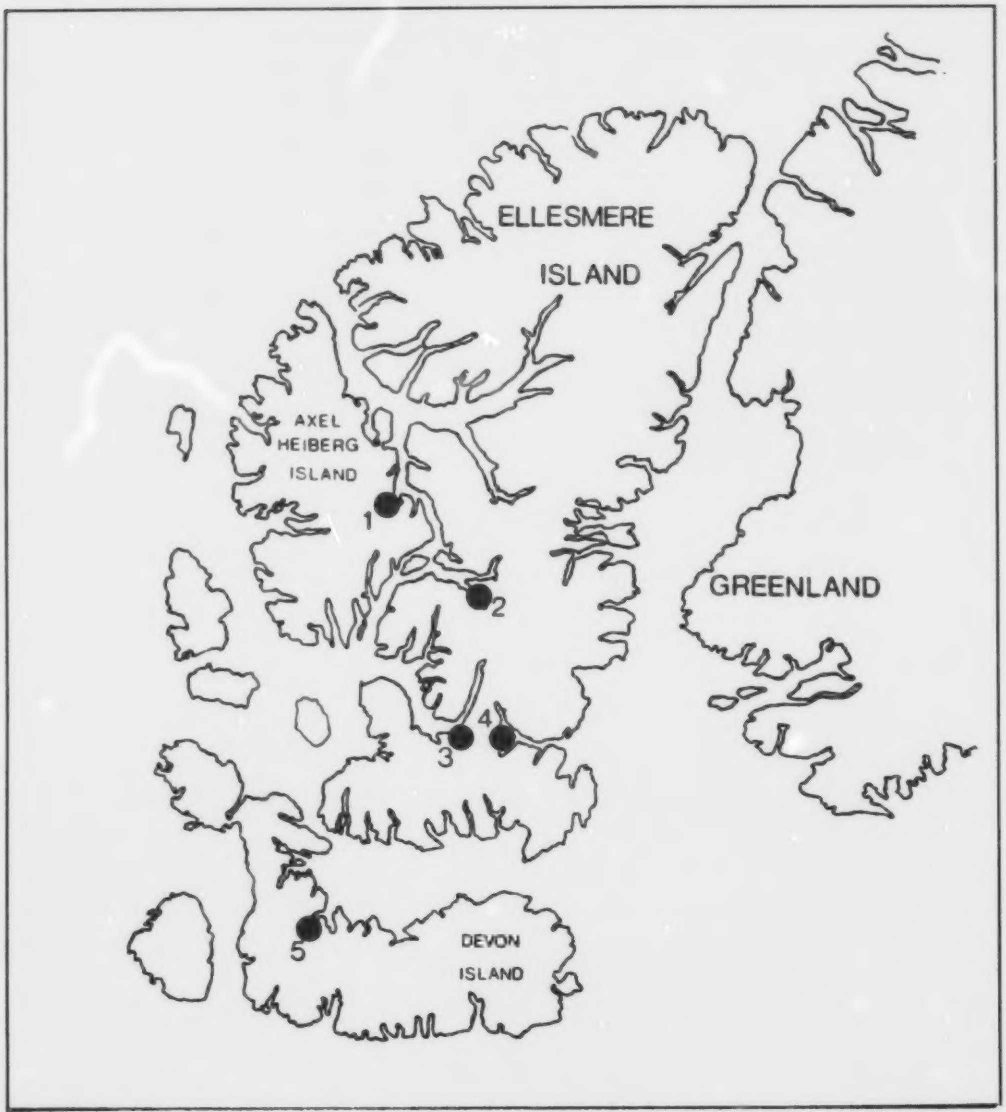

ELLESMERE
ISLAND
AXEL
HEIBERG
ISLAND
1
2
3
4
5
GREENLAND
DEVON
ISLAND

FIGURE 1: Distribution of terrestrial vertebrate - bearing localities of Tertiary age on Ellesmere, Axel Heiberg, and Devon islands; 1. Mokka Fiord; 2. Bay Fiord-Strathcona Fiord; 3. Stenkul Fiord; 4. Swinnerton Peninsula; 5. Haughton Astrobleme.

vertebrate records begin to form a picture of evolutionary and environmental features of high-latitudes before the Pleistocene - especially when combined with increasingly complete records of fossil plants.

TERRESTRIAL FOSSILS OF TERTIARY AGE IN THE ARCTIC

Among the many Tertiary rock units in northern polar regions, fossil plants are known from northern Siberia, northern Alaska, the Mackenzie Delta, Spitsbergen, Greenland, and the Canadian Arctic Archipelago (Axelrod 1984, and references cited therein). Fossil plants were found by earlier explorers of the Arctic Islands, especially in the widely distributed late Cretaceous to Eocene (and possibly Oligocene) Eureka Sound Group, in which well preserved wood and leaves were reported by Greely and Schei, among others (Troelsen 1950). More recent studies have augmented the known Eureka Sound macroflora and added a good palynological record (Hickey *et al.* 1983; Miall 1986; Ricketts 1986; Ricketts and McIntyre 1986). The younger (?Oligocene to Pliocene) Beaufort Formation, first described from Prince Patrick Island (Tozer 1956), and now recognized across the archipelago, contains fossil wood, leaves, seeds, and pollen (Matthews 1987; Matthews *et al.* this volume). These plant remains indicate that during the Tertiary the Arctic was far different from today: the floras of the Eureka Sound Group contain a rich record of the large deciduous gymnosperms *Metasequoia* and *Glyptostrobus*, other trees including *Betula*, *Cercidiphyllum*, and *Platanus*, a variety of understory ferns and other plants, *Equisetum*, and aquatics such as *Salvinia* and the lotus *Nelumbo*. Presence of plants whose modern relatives flourish only where freezing temperatures are rare or absent indicate that there were warm-temperate climatic conditions at the time of deposition. Floras from the younger Haughton and Beaufort formations contain trees and other plants that document cooler climates. The Beaufort Formation contains evidence of floral changes indicative of progressive climatic cooling through its temporal range (Matthews, *et al.* this volume).

Terrestrial vertebrates are less widespread in the Arctic Tertiary. Where they occur in Eocene and Miocene deposits in the Arctic Islands, they are associated with good records of fossil plants. Both lines of evidence can be used to reconstruct their high latitude habitats.

THE EOCENE VERTEBRATE RECORD

Four exposures of the Eureka Sound Group have produced terrestrial fossil vertebrates (Figure 1). Three are on central Ellesmere Island: Bay Fiord-Strathcona Fiord, discovered in 1975 (Dawson *et al.* 1976); Stenkul Fiord, discovered in 1982; and Swinnerton Peninsula, discovered in 1984. The fourth area is along Mokka Fiord, eastern Axel Heiberg Island, discovered in 1987. These localities occur between 77° and 79° 45'N. In every case, the fossils occur high in the Eureka Sound Group, in the Margaret and Mokka Fiord formations of Miall (1986), which are at least partly equivalent to the Iceberg Bay Formation of Ricketts (1986). Interbedded sandstones, siltstones, mudstones and coals characterize the fossiliferous parts of the group. Fossils occur both in fine-grained siltstones, where aquatic forms tend to be predominant, and in sandstones, especially those with ironstone nodules, where land mammals are more frequent. Rocks suggest coastal delta plains, river borders, and coal swamps; the fauna reflects this habitat in having many aquatic lower vertebrates (Figure 2).

Although taxonomic assignments of members of the Eureka Sound fauna, especially the mammals, are still preliminary, Table 1 gives an idea of faunal composition. Two faunal levels have been recognized, but only an emydid turtle, a taeniodont and a brontothere have been found in the uppermost level. The age of the two faunal levels can be estimated by biostratigraphic methods, although the lower level contains a mix of vertebrate temporal ranges not encountered in more southerly land-mammal assemblages. The lower fossiliferous level is probably early Eocene, and the upper level, early Bridgerian (middle Eocene). These are not precise assignments, but all that are warranted at this stage.

Prior to discovery of this high latitude fauna, plate-tectonics as well as faunal composition from mid-latitudes had provided evidence for an early Eocene land-connection between North America and Europe across the North Atlantic (McKenna 1975). The Arctic fauna corroborates this connection (West *et al.* 1977). Geographic affinities of members of the Eureka Sound faunas are preponderantly North American, all families being shared. Outside of their occurrence in the Eureka Sound Group, the salamander *Piceoerpeton*, the kinosternid, the plagiomenids, and *Lambdotherium* are known only from North American mid-latitudes. With those exceptions and the endemic forms discussed below, all faunal elements except the anosteirine and the taeniodont (Asian connections must be sought for

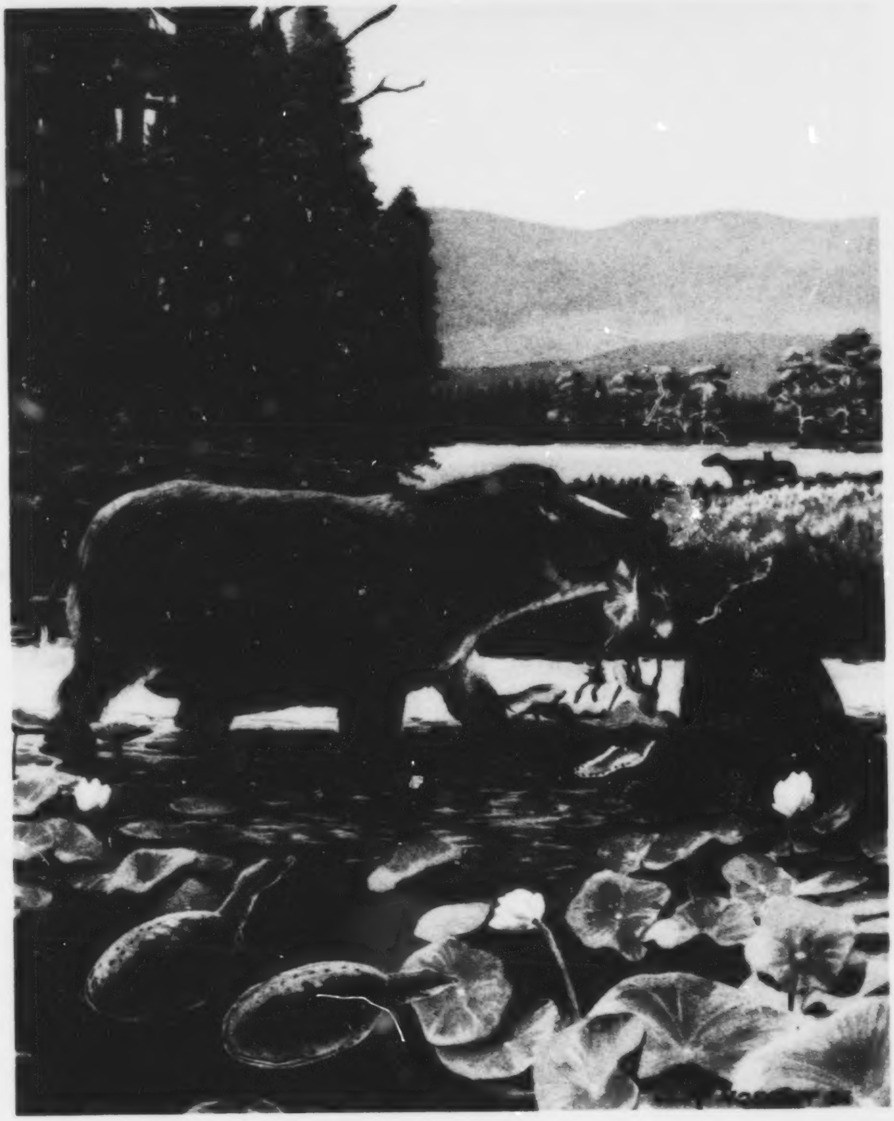


FIGURE 2: A landscape in the early Eocene showing some flora and fauna of the Eureka Sound Group on Ellesmere Island. In a deltaic habitat near a stand of dawn redwoods (Metasequoia), the large pantodont (Coryphodon) eats lotus (Nelumbo). A small alligator (Allognathosuchus) and soft-shelled turtles (Trionyx) occupy the foreground. Perissodactyls (Hyrachyus) browse in the middle distance. Reconstruction by Clifford J. Morrow, Jr.

TABLE 1: EUREKA SOUND FAUNAL LIST.[1]

- Class Osteichthys
  - Family Lepisosteidae
    - ?*Lepisosteus* sp.
  - Family Amiidae
    - *Amia fragosa*
    - *Amia* cf. *A. uintaensis*
  - Family Esocidae
    - *Esox* sp.
- Class Amphibia
  - Family ?Scapherpetontidae
    - *Piceoerpeton* cf. *P. willwoodense*
- Class Reptilia
  - Order Testudinata
    - Family Emydidae (abundant; both levels)
      - two emydines, genus and species unidentified
      - emydine unidentified
    - Family Testudinidae
      - *Geochelone* sp.
    - Family Kinosternidae
      - kinosternine genus and species unidentified
    - Family Carettochelyidae
      - anosteirine genus and species unidentified
    - Family Trionychidae (abundant)
      - *Trionyx* sp.
      - cryptodire genus *incertae sedis*
  - Order Squamata
    - Family Anguidae
      - glyptosaurine genus and species unidentified
      - subfamily *incertae sedis*
    - Family Varanidae
      - genus and species unidentified
    - Family Boidae
      - erycine unidentified
  - Order Crocodilia
    - Family Crocodylidae
      - *Allognathosuchus sp.* (abundant)
- Class Aves
  - Order Diatrymiformes
    - Family Diatrymatidae
      - *Diatryma* sp.
  - Order Charadriiformes
    - Family Presbyornithidae
      - *Presbyornis* sp.
- Class Mammalia
  - Order Multituberculata
    - Family Neoplagiaulacidae
      - *Neoplagiaulax* sp.

TABLE 1: (concluded)

- Order Leptictida
  - Family Leptictidae
    - species undetermined
- Order Pantolesta
  - Family Pantolestidae
    - cf. *Pantolestes* and *Chadronia*
- Order Primates
  - Family Paromomyidae
    - new genus and species
    - new species
- Order Dermoptera (abundant)
  - Family Plagiomenidae
    - cf. *Plagiomene*, 4 or 5 species
- Order Rodentia
  - Family Ischyromyidae
    - 3 species
- Order Taeniodonta
  - Family Stylinodontidae
    - genus undetermined (upper level)
- Order Pantodonta (abundant)
  - Family Coryphodontidae
    - *Coryphodon* sp.
- Order Acreodi
  - Family Mesonychidae
    - cf. *Mesonyx* spp.
- Order Creodonta
  - ?Family Hyaenodontidae
    - genus undetermined
    - *Prolimnocyon* sp.
- Order Carnivora
  - Family Miacidae
    - *Viverravus* sp.
    - miacine cf. *Uintacyon* and *Vulpavus*
- Order Perissodactyla (abundant)
  - Family Hyrachyidae
    - *Hyrachyus* sp.
- Family Brontotheriidae
    - ?*Lambdotherium* sp.
    - cf. *Manteoceras* sp. (upper level)

---

[1] Identifications from Estes and Hutchison (1980), McKenna (1980), with additions from later field work.

these) are shared with Europe. Several other faunal elements are also shared with Asia. In total, the Eureka Sound fauna probably was not geographically isolated but occupied part of a vast Holarctic biogeographic province.

Some of the Arctic fauna, notably the unidentified cryptodire, the species of *Allognathosuchus*, and the diversity of plagiomenids, appear to have been endemic to the Arctic. Such endemism may be related to limiting environmental conditions, in which warm climates were coupled with the characteristic polar light-regime featuring continuous darkness from about mid-November until mid-February and continuous light from roughly May until mid-August. That such high-latitude light conditions would have prevailed has been shown by paleomagnetic work demonstrating that, during the Eocene, Ellesmere and Axel Heiberg islands were situated well within the Arctic Circle, slightly less than 3° farther south than their present latitudes (McKenna 1983). This is not a significant difference from today in terms of polar light-regime. Seasonality, which in this case would be light-dark, not warm-cold induced, is indicated both by marked growth rings in fossil wood from the Eureka Sound Group and by growth rings in some of the bones of the large salamander, *Piceoerpeton*.

The fossil-plant evidence for warm climatic conditions is strongly supported by the terrestrial vertebrates: the large, non-burrowing tortoise *Geochelone*, the varanid lizard, and the alligator *Allognathosuchus* indicate that freezing temperatures were not characteristic of the habitat. Among the mammals, the closest modern relatives of the primates and dermopterans inhabit tropical regions.

Because the Arctic Eocene combination of warm temperatures and polar light conditions does not exist today, it is difficult to interpret animal and plant responses to these extinct environmental conditions. All trees from the Eureka Sound deposits are deciduous, possibly an adaptation to the absence of sunlight in the polar winter (personal communication, Leo J. Hickey). Low diversity of the fauna, compared to Eocene mid-latitude assemblages (West *et al.* 1977; McKenna 1980), suggests that the environment was stressful. Absence of contemporary groups well-represented farther south, such as marsupials, diverse primates, condylarths and artiodactyls, also indicate limiting factors.

Vertebrate responses to the dark winters were probably varied. Migration might have been an option for the large herbivore *Coryphodon*, and some carnivores might have followed this prey. The smaller mammals, the amphibians and reptiles probably did not leave the Arctic in the winter, and dormancy or hibernation might have been practised by some of them (Estes and Hutchison 1980). Other Arctic Eocene animals probably survived the dark winter by feeding on dry fruits, seeds, roots and tubers. One of the turtles in the fauna, the endemic cryptodire, was a mollusc-eater, a food supply that would have been available year around (Estes and Hutchison 1980). Development of nocturnality might have been a useful Arctic specialization.

The case of the plagiomenid dermopterans is interesting. Relatively rare in mid-latitude North American Eocene deposits, they are the most abundant and diverse small mammals in the Arctic Eocene, represented by about five species. Clearly the plagiomenids were well adapted to this habitat, possibly finding homes in the extensive forests (Figure 3). Their diversity might reflect a relatively recent colonization of the area, accompanied by a radiation into fresh niches.

While much remains to be explained about high-latitude evolutionary developments in the Eocene, the fauna of the Eureka Sound Group provides concrete evidence not only that polar regions were habitable, but also that they nurtured a fauna unlike any other. Except for this glimpse, vast stretches of the northern Holarctic provide no known Eocene terrestrial fossil vertebrates. The closest comparable record is from much farther south (about 50°N) in the London Basin.

THE MIOCENE VERTEBRATE RECORD

The only known arctic Miocene terrestrial vertebrates occur in Haughton Astrobleme, a nearly circular meteorite impact-crater about 20 km in diameter, located at 75° 22'N, near the north-central coast of Devon Island (Figure 1). The impact that formed the crater has been dated at between 22 and 23 million years (22.4 ± 1.4 million years ago by the fission-track method (Omar *et al.* 1987); and 23.4 ± 1.0 million years ago by ^{40}Ar-^{39}Ar analysis (Jessberger 1988)). These dates fall at the beginning of the early Miocene and can be used to mark the beginning of a lake that developed in the crater soon after it formed. The vertebrate fossils, with associated pollen and megaflora, occur in remnants of sediments deposited in the lake - the Haughton Formation (Frisch and Thorsteinsson 1978; Hickey *et al.* 1988).

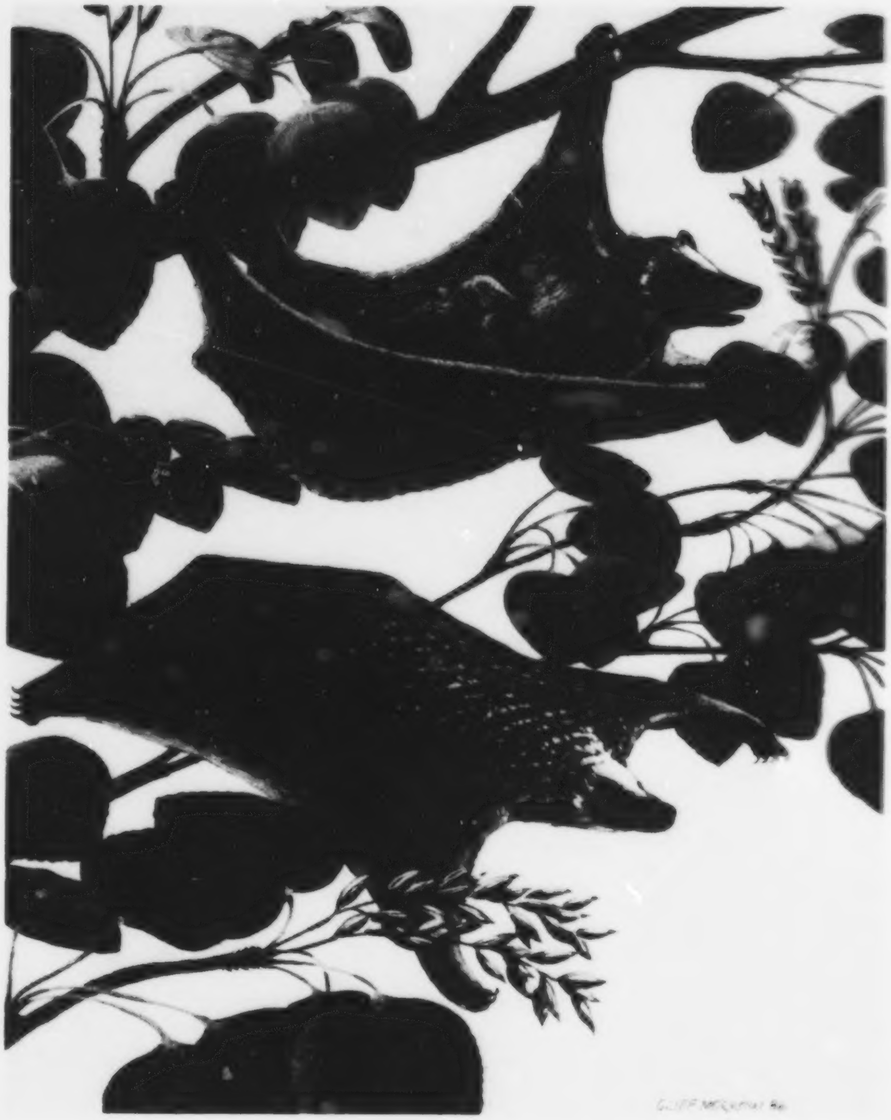


FIGURE 3: Plagiomenid dermopterans, the most abundant small mammals in the Eureka Sound fauna, are probably related to modern "flying lemurs". This reconstruction suggests similar gliding adaptations in the Ellesmere Island Eocene plagiomenids. They are shown in an Eocene Cercidiphyllum tree, remains of which occur frequently with fossil vertebrates in the Eureka Sound Group. Reconstruction by Clifford J. Morrow, Jr.

Vegetation during deposition of the Haughton Formation consisted of a mixed conifer-hardwood forest dominated by the conifers *Pinus*, *Tsuga*, and *Larix*, and the hardwoods *Betula*, *Alnus*, and *Corylus*. Ericaceous pollen is abundant in the formation, suggesting presence of boreal heath. Cool-temperate conditions in a coastal habitat are indicated by the total flora (Hickey *et al.* 1988; Barnosky and Dawson, in press).

Vertebrates from the Haughton Lake deposits include two kinds of salmoniform fishes: a trout (*Eosalmo* sp.) and a smelt-like fish (cf. *Osmerus* sp.). One bird, a swan (Tribe Cygnini) is present. Mammals include: a shrew (Heterosoricinae); a primitive rabbit (Leporidae); primitive rhinoceros (Rhinocerotidae); and an artiodactyl of uncertain affinities. Many rabbit specimens are known, but the other taxa are rare. The rhinoceros is represented by a nearly complete, though broken, skeleton.

None of the members of this vertebrate fauna shows close affinities with the previously mentioned Eocene Eureka Sound fauna: this might not be expected in light of seemingly small temporal and climatic differences. Perhaps the highly-distinctive morphologies of the Haughton rhinoceros and artiodactyl indicate that some environmental or geographic isolating mechanism separated the Devon Island fauna from others, and had done so for some time. Lancaster Sound may have become an effective, open-water barrier to north and south movements of terrestrial vertebrates.

This vertebrate assemblage has some paleoenvironmental significance. For example, trout and smelt are northern cool-water fishes. Today swans do not occur as far north as Devon Island, again suggesting that the Miocene was milder than present. The mammals are less indicative of climate.

CONCLUSIONS

The extinct Tertiary environments now known from Canada's Arctic have produced unique floral and faunal developments in an area that had particular environmental conditions. The Eocene vertebrate fauna was not geographically isolated, but had a unique composition probably due to limiting environmental conditions. Evolutionary innovations among the Arctic vertebrates may have proved adaptive farther south as the climate cooled later in the Tertiary.

The Miocene vertebrate record does not represent a normally-balanced fauna. Endemism in that fauna suggests that it developed following a period of geographic isolation.

Neither Eocene nor Miocene faunas show connections to the modern Arctic terrestrial vertebrate faunas, which developed following the complex biotic remodelling of the Pleistocene.

ACKNOWLEDGEMENTS

I sincerely thank Dr. Ray Thorsteinsson, Geological Survey of Canada, for his initial encouragement to undertake the search for fossil vertebrates in the Cenozoic of the Canadian Arctic Islands. Support from Polar Continental Shelf Project, Energy, Mines and Resources, Canada, and the Committee for Research and Exploration of the National Geographic Society made the field work not only possible but also productive. The Paleobiology Division, National Museum of Natural Sciences, Ottawa, is the repository for these fossil vertebrates. I particularly acknowledge the field and research help of my colleagues: Drs. H. de Bruijn, L.J. Hickey, J.H. Hutchison, M.C. McKenna, S. Olson, P. Ramaekers, R. Schoch, G. Smith, R.M. West, and Messrs. K.R. Johnson, C.J. Morrow and G. Whalen.

REFERENCES

Axelrod, D.I. 1984. An interpretation of Cretaceous and Tertiary biotas in polar regions. Palaeogeography, Palaeoclimatology, Palaeoecology 45:105-147.

Barnosky, C.W. and M.R. Dawson. (in press). Pollen and vertebrates of the early Neogene Haughton Formation, Devon Island, Arctic Canada. Arctic.

Dawson, M.R., R.M. West, W. Langston, Jr., and J.H. Hutchison. 1976. Paleogene terrestrial vertebrates: northernmost occurrence, Ellesmere Island, Canada. Science 192:781-782.

Estes, R. and J.H. Hutchison. 1980. Eocene lower vertebrates from Ellesmere Island, Canadian Arctic Archipelago. Palaeogeography, Palaeoclimatology, Palaeoecology 30:325-347.

Frisch, T. and R. Thorsteinsson. 1978. Haughton Astrobleme: a mid-Cenozoic impact crater Devon Island, Canadian Arctic Archipelago. Arctic 31:108-124.

Hickey, L.J., R.M. West, M.R. Dawson, and D.K. Choi. 1983. Arctic terrestrial biota: paleomagnetic evidence of age disparity with mid-northern latitudes during the Late Cretaceous and Early Tertiary. Science 221:1153-1156.

Hickey, L.J., K.R. Johnson, and M.R. Dawson. 1988. The stratigraphy, sedimentology, and fossils of the Haughton Formation: a post-impact crater-fill, Devon Island, N.W.T., Canada. Meteoritics 23:221-231.

Jessberger, E.K. 1988. ^{40}Ar-^{39}Ar dating of the Haughton impact structure. Meteoritics 23:233-234.

Matthews, J.V., Jr. 1987. Plant macrofossils from the Neogene Beaufort Formation on Banks and Meighen islands, District of Franklin. Geological Survey of Canada, Paper 87-1A:73-87.

McKenna, M.C. 1975. Fossil mammals and early Eocene North Atlantic land continuity. Annals of the Missouri Botanical Garden 62:335-353.

______. 1980. Eocene paleolatitude, climate, and mammals of Ellesmere Island. Palaeogeography, Palaeoclimatology, Palaeoecology 30:349-362.

______. 1983. Holarctic landmass rearrangement, cosmic events, and Cenozoic terrestrial organisms. Annals of the Missouri Botanical Garden 70:459-489.

Miall, A.D. 1986. The Eureka Sound Group (Upper Cretaceous-Oligocene), Canadian Arctic Islands. Bulletin of Canadian Petroleum Geology 34(2):240-270.

Omar, G., K.R. Johnson, L.J. Hickey, M.R. Dawson, and C.W. Barnosky. 1987. Fission-track dating of Haughton Astrobleme and included biota, Devon Island, Canada. Science 237:1603-1605.

Ricketts, B.D. 1986. New formations in the Eureka Sound Group, Canadian Arctic Islands. Geological Survey of Canada, Paper 86-1B:363-374.

Ricketts, B.D. and D.J. McIntyre. 1986. The Eureka Sound Group of eastern Axel Heiberg Island: new data on the Eurekan Orogeny. Geological Survey of Canada, Paper 86-1B:405-410.

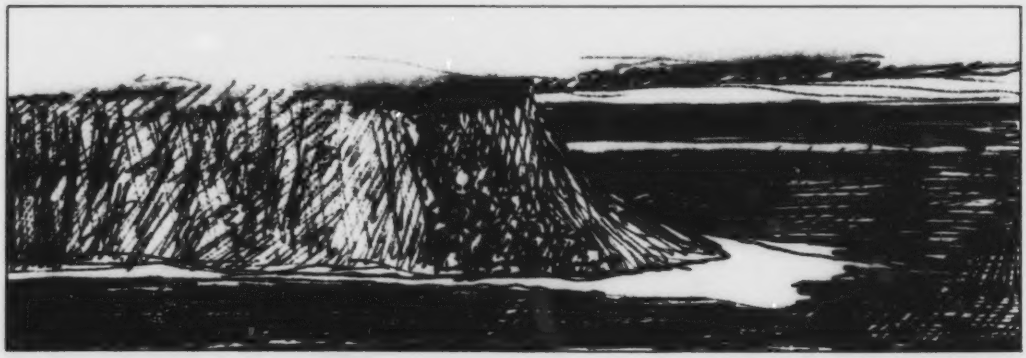
Thorsteinsson, R. and E.T. Tozer. 1957. Geological investigations in Ellesmere and Axel Heiberg islands, 1956. Arctic 10:2-31.

Tozer, E.T. 1956. Geological reconnaissance, Prince Patrick, Eglinton, and western Melville islands, Arctic Archipelago, Northwest Territories. Geological Survey of Canada, Paper 55-5:1-32.

Troelsen, J.C. 1950. Contributions to the geology of northwest Greenland, Ellesmere Island and Axel Heiberg Island. Meddelelser om Grønland 149(7):1-85.

West, R.M., M.R. Dawson, and J.H. Hutchison. 1977. Fossils from the Paleogene Eureka Sound Formation, N.W.T., Canada: occurrence, climatic and paleogeographic implications. In: Paleontology and Plate Tectonics. Edited by: R.M. West. Milwaukee Public Museum, Special Publications in Biology and Geology 2:77-93.

West, R.M., L.J. Hickey, M.R. Dawson, and A.D. Miall. 1981. Upper Cretaceous and Paleogene sedimentary rocks, eastern Canadian Arctic and related North American areas. In: Geology of the North Atlantic Borderlands. Edited by: J.W. Kerr and A.J. Fergusson. Canadian Society of Petroleum Geologists, Memoir:279-298.



Illustrated by Brenda Carter

PLANT AND INSECT FOSSILS FROM THE LATE TERTIARY BEAUFORT FORMATION ON PRINCE PATRICK ISLAND, N.W.T.

John V. Matthews, Jr.[1], L.E. Ovenden[1], and J.G. Fyles[1]

Abstract: The late Tertiary Beaufort Formation, which is exposed on many of the western islands of the Canadian Arctic Archipelago, contains well preserved plant and insect fossils. This paper is a preliminary report on new finds from Prince Patrick Island. Organic deposits from 14 sites have been studied. The fossils discussed here come primarily from one, Devaney Section 1, which is located near the site where the Beaufort Formation was first defined.

At least 96 species of vascular plants, 49 species of bryophytes and 80 species of arthropods are listed. Some plant remains represent extinct genera (e.g. Epipremnum, Aracites), while many of the others may represent extinct species. Trees account for only about 11% of the flora (Pinus strobus type, Picea, Abies, Larix, Thuja, Betula and Populus); nevertheless Prince Patrick Island was probably forested at the time of deposition of these beds, with a mean July temperature at least 9°C warmer than present. In addition to Betula, Alnus, Cornus stolinifera and various Ericaceae, the shrub component of the flora contained taxa such as Decodon and Comptonia, which do not reach northern areas today, as well Weigela which is extinct in North America. The flora also includes typical arctic/alpine plants such as Oxyria, Dryas and Saxifraga oppositifolia. Most bryophyte fossils from Prince Patrick Island deposits represent species belonging to the circumpolar element of the modern moss flora.

The majority of insect fossils represent beetles that now live in stream-side communities. Some have been recorded from Meighen Island, but in general the Prince Patrick Island fauna is more similar to that seen in "upper Beaufort" deposits on northern Banks Island.

Despite some floristic differences, it has been argued on the basis of plant fossils that "upper Beaufort" floras from northern Banks, Prince Patrick and Meighen islands are all about the same age. If so, the latest information from Meighen Island (Foraminifera and Sr-isotope dates) means that they date to the Pliocene (probably early Pliocene) rather than late Miocene as previously thought.

Résumé: La Formation de Beaufort, qui date du Tertiaire supérieur et affleure dans maintes îles de l'ouest de l'Archipel arctique canadien, renferme des plantes et des insectes fossiles bien conservés. Le présent article est un rapport préliminaire sur les découvertes récentes faites dans l'île Prince Patrick. Les gisements organiques de 14 sites ont été étudiés. La majorité des fossiles analysés ici proviennent de la coupe Devaney 1, située près du site où la Formation de Beaufort a initialement été définie.

Au moins 95 espèces de plantes vasculaires, 49 espèces de bryophytes et 80 espèces d'arthropodes sont représentées. Certains reste végétaux appartiennent à des genres aujourd'hui disparus (par ex. Epipremmum, Aracites), et de nombreux autres, à des espèces disparues. Les arbres ne comptent que pour 11 % environ de la flore (Pinus strobus, Picea, Abies, Larix, Thuja, Betula et Populus); néanmoins, à l'époque de la mise en place de ces gisements, l'île Prince Patrick était probablement recouverte d'arbres et la température moyenne en juillet était supérieure de 9°C au moins à celle d'aujourd'hui. Outre Betula, Alnus, Cornus stolinifera et quelques Éricacées, la flore arbustive incluait des taxons tels que Decodon et Comptonia, aujourd'hui disparus des régions septentrionales, ainsi que Weigela que l'on ne rencontre plus en Amérique du Nord. La flore incluait également des plantes arctiques-alpines typiques telles que Oxyria, Dryas et Saxifraga oppositifolia. Presque tous les bryophytes fossiles présents dans les gisements de l'île Prince Patrick représentent des espèces du domaine circumpolaire de la flore hygrophile actuelle.

La plupart des insectes fossiles sont des coléoptères qui, de nos jours, vivent sur les rives des cours d'eau. Certains ont été apparentés à ceux de l'île Meighen, mais, en général, la faune de l'île Prince Patrick ressemble davantage à celle présente dans les gisements de la Formation de Beaufort, dans le nord de l'île Banks.

Malgré quelques différences floristiques, les flores de la Formation de Beaufort du Tertiaire supérieur des îles Banks, Prince Patrick et Meighen seraient à peu près contemporaines, comme l'indique l'étude des plantes fossiles. Si c'est le cas, les dernières données recueillies à l'île Meighen (datation au moyen des Foraminifères et du Sr isotopique) les feraient dater du Pliocène (probablement du Pliocène inférieur) plutôt que du Miocène supérieur comme on le pensait.

INTRODUCTION

The late Tertiary Beaufort Formation, which is exposed on many of the western Queen Elizabeth Islands (QEI) and on Banks Island (Figure 1), is a source of well-preserved plant and insect fossils (Hills 1975; Matthews 1977A). It consists mostly of alluvial sands containing detrital organic debris. Prior to this report, most collections of Beaufort Formation fossils were from widely separated exposures on northern and southern Banks Island and on Meighen Island (Hills 1975; Hills *et al.* 1974; Hills and Matthews 1974; Kuc and Hills 1971; Kuc 1973; Matthews 1977A, 1987A, 1989) (Figure 1). Except for the extensive data from Meighen Island and a brief reference by Hills (1975) to fossils from Prince Patrick and Ellef Ringnes islands little has been published, or indeed is known about the flora and fauna of the Beaufort Formation from the western QEI. Prince Patrick Island represents an especially embarrassing gap in our knowledge because it is the place where the Beaufort Formation was first recognized by Tozer (1956). This paper is intended as a step in redressing this problem. It lists and discusses the chronological and paleoenvironmental implications of plant and insect fossils from a few of the 56 sites visited and studied by one of the authors (J.G.F.) and Jon Devaney (then with the Geological Survey of Canada) during the summer of 1987.

---

[1] Terrain Sciences Division, Geological Survey of Canada, Ottawa, Ontario K1A 0E8
Geological Survey of Canada Contribution 39188

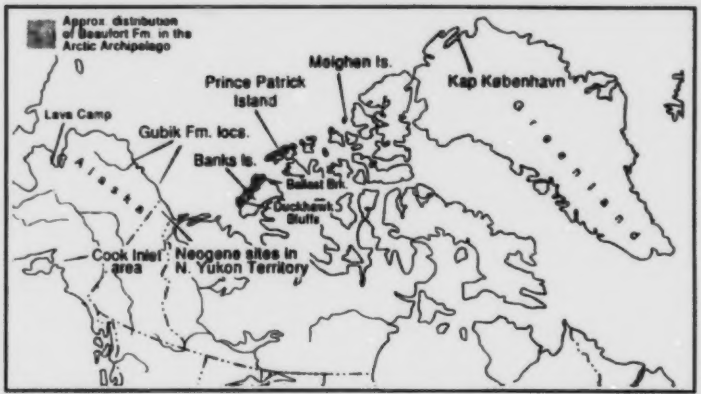


FIGURE 1: Late Tertiary sites mentioned in the text, including Beaufort Formation localities in the Arctic Archipelago.

THE BEAUFORT FORMATION ON PRINCE PATRICK ISLAND

The name Beaufort Formation was first used for unconsolidated, wood-bearing sands and gravels in the Mould Bay area of Prince Patrick Island (Figures 1,2) (Tozer, 1956). The strata making up this formation on Prince Patrick Island comprise a single lithostratigraphic unit characterized by recurring intervals of cross-bedded, medium to coarse sand and pebbly sand interspersed with subsidiary amounts of gravel, rippled and horizontal fine sand, silty or clayey "mud", wood-beds and beds of fine plant detritus interlayered with fine sediments (Figure 3). The sediments represent an unlithified, sandy, braided river deposit - the coarse sediments being channel and bar deposits while the finer and wood-bearing strata are low-stage overbank deposits (Fyles, unpublished abstract 1987; Devaney and Fyles 1988).

These deposits form a wedge, elongated northeast parallel to the length of the island (Figure 2), which thickens to the northwest and presumably extends offshore beneath the Arctic Ocean. The braided streams that deposited the Beaufort sediments appear to have flowed northwestward across the belt. The Beaufort Formation rests unconformably on Devonian to Cretaceous bedrock, and is capped disconformably by a thin unit of gravel (commonly with boulders) which forms an upland plain sloping downward to the northwest. The stratigraphic and sedimentological information presented above and the paleontological information presented below refer almost entirely to the thin, southeastern margin of the Beaufort belt on Prince Patrick Island, where almost all the good stream-cut exposures occur. As yet, very little is known about the thick Beaufort deposits beneath the western part of the island.

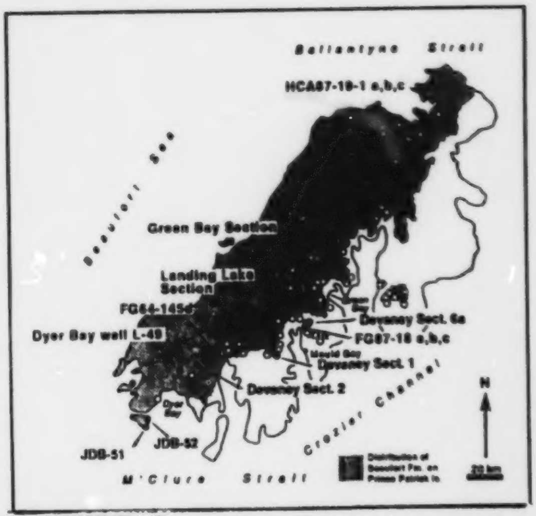

Ballantyne Strait
HCA87-19-1 a,b,c
Beaufort Sea
Green Bay Section
Landing Lake Section
FG84-145d
Dyer Bay well L-49
Devaney Sect. 6a
FG87-18 a,b,c
Mould Bay
Devaney Sect. 1
Devaney Sect. 2
Dyer Bay
JDB-51
JDB-52
Crozier Channel
M'Clure Strait
Distribution of Beaufort Fm. on Prince Patrick Is.
N
20 km

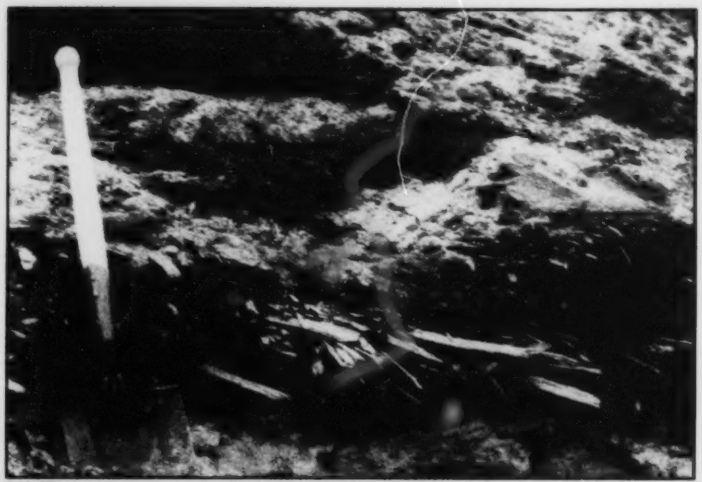
FIGURE 2: Prince Patrick Island showing sites visited and studied by Fyles and Devaney in 1987. Black dots indicate sites from which fossils have been isolated (as of May 1988). Stippling indicates areas where Beaufort Formation outcrops.

Most of the fossils discussed here come from the finer detrital facies found in both cross-stratified and horizontally-bedded sequences. They occur either as wood and fine detritus in sand and silt, or as mats of moss-rich detritus. None of the Prince Patrick exposures examined to date has revealed autochthonous peats or forest-beds with tree stumps in growth position (Fyles, unpublished abstract 1987). The Landing Lake and Green Bay sites contain what appear to be autochthonous peat beds, but they may post-date the Beaufort Formation.

SAMPLE SITES

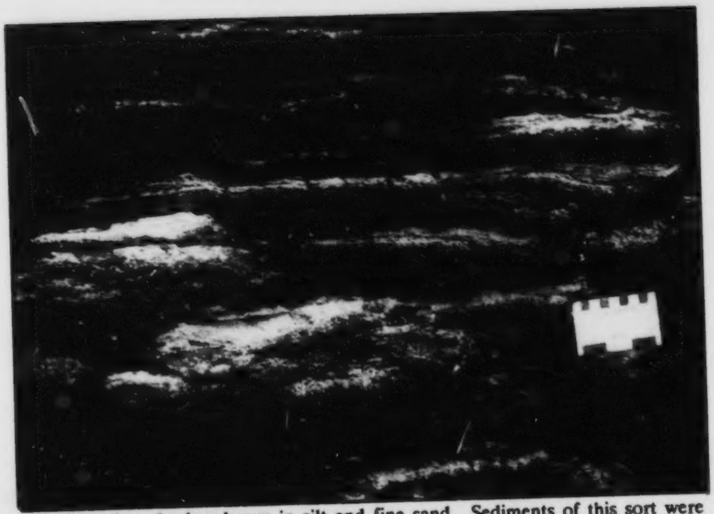
Virtually all of the sites examined by Fyles and Devaney contain plant macrofossils. Figure 2 shows sites (black dots) that have been studied to date. Only a few of the

FIGURE 3: The Beaufort Formation on Prince Patrick Island:

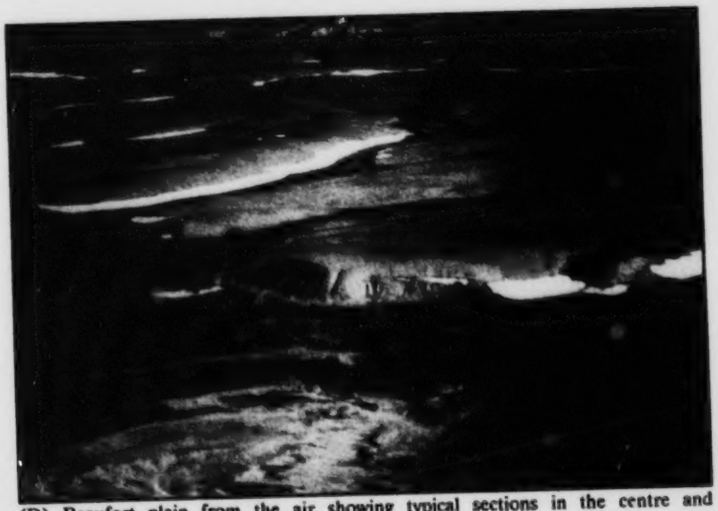


(A) Typical sorted woody-detrital bed containing flattened and rounded wood - not the best source of macrofossils.

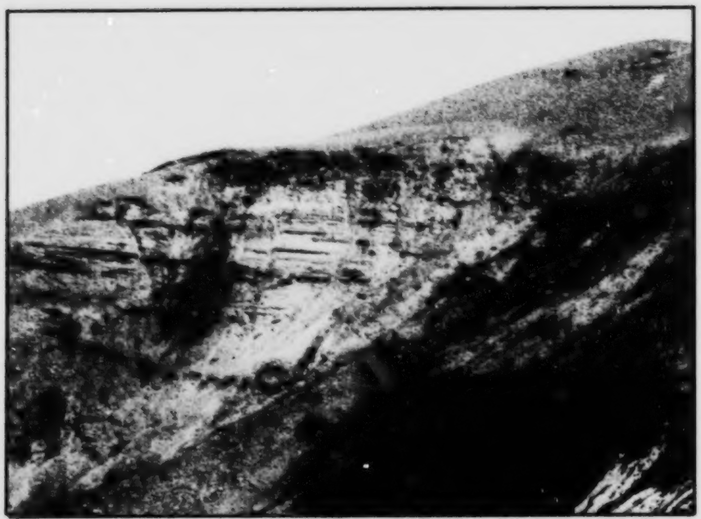
(B) Unsorted, angular wood in silt at the level of sample JBD-12, Devaney Section 1 (Figure 4). This type of deposit may yield macrofossils.



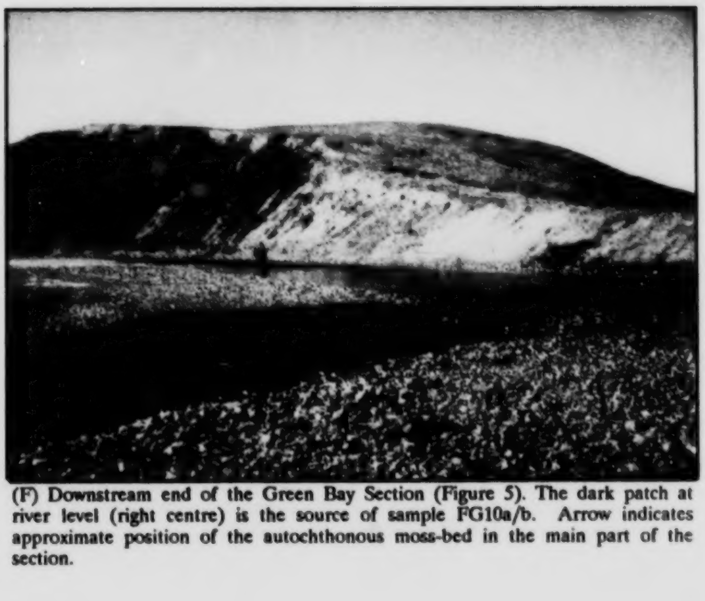
(C) Fine plant-detritus layers in silt and fine sand. Sediments of this sort were the source of sample FG87-1e at Devaney Section 1 (Figure 4), and are the best type for delicate macrofossils, allochthonous mosses and pollen.



(D) Beaufort plain from the air showing typical sections in the centre and background.



(E) Upper part of Devaney Section 1 (Figure 4). Break in slope represents change from more organic sediments below and inorganic sand, with the break in slope being approximately at the level of sample JBD-12. Large dark area in right foreground is the 1 m thick horizon of woody beds and fine plant detritus with silt and fine sand at the base of the section (Figure 4).



(F) Downstream end of the Green Bay Section (Figure 5). The dark patch at river level (right centre) is the source of sample FG10a/b. Arrow indicates approximate position of the autochthonous moss-bed in the main part of the section.

samples currently under study are discussed here, and most of them (Tables 1-3) come from Devaney Section 1 (Figure 4), which is located near the area where Tozer (1956) first defined the Beaufort Formation. Section 1 is a composite of exposures, with about 40 m of Beaufort sediments extending over a lateral distance of approximately 200 m. One kilometre east of the site, the Beaufort Formation wedges out against the higher-standing upper Devonian sandstone.

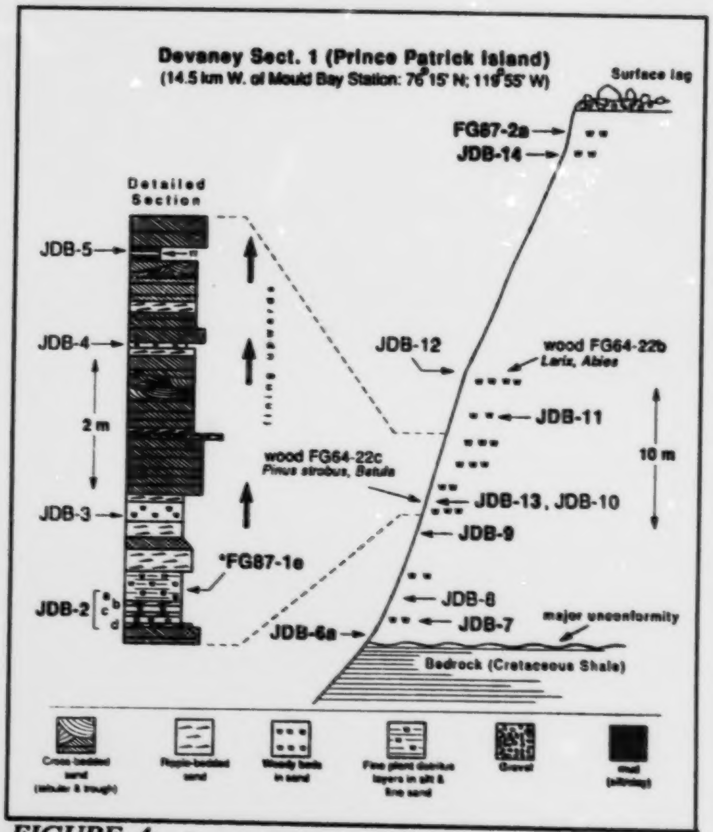

Devaney Sect. 1 (Prince Patrick Island)
(14.5 km W. of Mould Bay Station: 76°15' N; 119°55' W)
Surface lag
FG87-2a
JDB-14
Detailed Section
JDB-5
JDB-4
2 m
JDB-3
JDB-2
a
b
c
d
fining upwards
*FG87-1e
JDB-12
wood FG64-22b
Larix, Abies
JDB-11
10 m
wood FG64-22c
Pinus strobus, Betula
JDB-13, JDB-10
JDB-9
JDB-8
JDB-7
JDB-6a
major unconformity
Bedrock (Cretaceous Shale)
Cross-bedded sand (tabular & trough)
Ripple-bedded sand
Woody beds in sand
Fine plant detritus layers in silt & fine sand
Gravel
mud (silt/clay)

FIGURE 4: Devaney Section 1, showing stratigraphic details in part of the section and sources of samples collected. Those shown in bold have been examined for macrofossils. The sample with an asterisk has also been studied for fossil pollen (see text). Wood identifications are from R.J. Mott (unpublished Geological Survey of Canada Palynological Report 68-4).

Several Devaney Section 1 samples (JDB-2, JDB-13, JDB-10, FG87-1e) are from a 1 m thick sequence (Figure 3e) of fine plant detritus interlayered with medium to fine sand and silt with tabular, rippled and cross-bedded laminae. Sample FG87-1e, one of the richest in plant and insect fossils, and the only one from the section that was examined for pollen (R.J. Mott, unpublished Geological Survey of Canada Palynological Report 87-11) is from the upper part of this organic zone. Its macrofossils are pooled with those of sample JDB-13b from approximately the same level at another part of the section (see heading "13&1e", Table 1). FG87-2a ("2a" in Table 1) comes from a 10 cm peaty layer beneath the surficial bouldery gravel, and represents the highest organic horizon exposed at the section. JDB-6a ("6a" in Table 1) consists of detrital organic matter in sand less than 1 m above bedrock (Figure 4). A few wood samples have also been identified from this and adjacent sections (R.J.Mott, unpublished Geological Survey of Canada Palynological Report 68-4).

The section from which samples FG87-18 a,b and c come is a 15 m thick sequence resting on an eroded bedrock surface with at least 5 m of relief. The fossils are from a 1.5 m unit of silty sand, silt and fine sand with multiple layers of fine plant detritus which lie above the 2 m unit of coarse pebbly sand that forms the base of the Beaufort sequence at the site.

The Green Bay Section (Figures 2, 3F, 5), 51 m above sea level at its base, is 12 km northwest of Green Bay. It differs from the other sites discussed because its top is a bench located approximately 40 m below the regional Beaufort surface. It is also one of the few sections containing autochthonous peat; although, as indicated below, this peat and overlying sediments probably post-date the Beaufort Formation. FG10a/2, which has yielded a flora and fauna slightly different from other Prince Patrick Island Beaufort Formation sites, was collected approximately 150 m downstream at river level in as moss-rich lens of wood and fine plant detritus up to 1 m thick enclosed in medium sand.

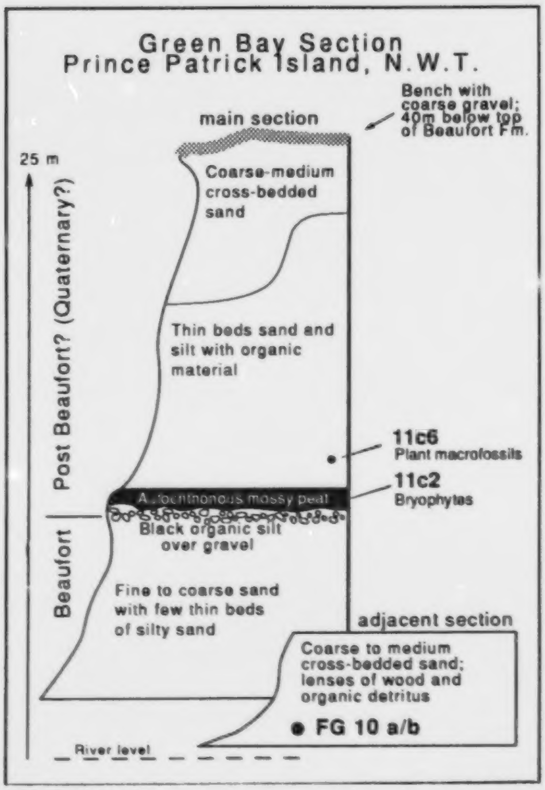

Green Bay Section
Prince Patrick Island, N.W.T.
Bench with coarse gravel; 40m below top of Beaufort Fm.
main section
25 m
Post Beaufort? (Quaternary?)
Beaufort
Coarse-medium cross-bedded sand
Thin beds sand and silt with organic material
11c6
Plant macrofossils
11c2
Bryophytes
Autochthonous mossy peat
Black organic silt over gravel
Fine to coarse sand with few thin beds of silty sand
adjacent section
Coarse to medium cross-bedded sand; lenses of wood and organic detritus
FG 10 a/b
River level

FIGURE 5: Generalized stratigraphy of the Green Bay exposure (Figure 3F) showing sources of samples FG10a/b and two samples from the autochthonous peat at the main section FG11c2 (Table 2) and the overlying peaty sediments (FG11c6).

The top of the Landing Lake Section (Figure 2) is also well below the Beaufort Formation surface, so it too might contain post-Beaufort sediments. The fossils come from a layer of moss-peat and enclosing sands with wood and other organic detritus. The moss-mat appeared in the field to be a fragment of a former surface layer that fell into a stream and subsequently was buried in the sandy alluvium. The mosses listed in Table 2 come from this autochthonous fragment; the vascular plants in Table 1 are from organic detritus in the enclosing sand. Note that Tables 1-4 are at the end of the paper.

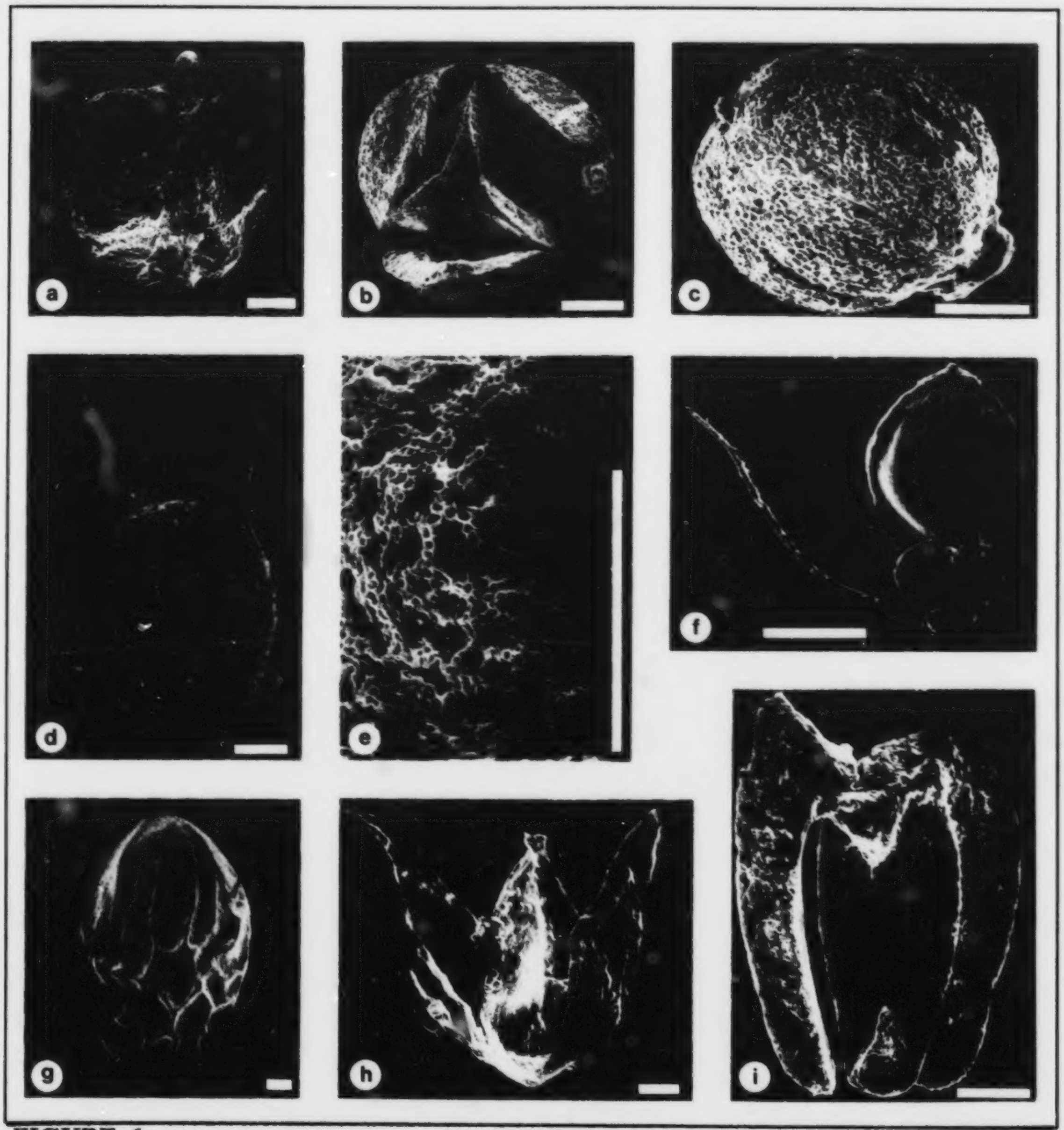


FIGURE 6: Electron Microscope images of plant macrofossils from the Beaufort Formation on Prince Patrick Island and related fossils. Scale bar=0.3 mm. (a) GSC-95881: Rumex sp., sample FG 87-18b. (b) GSC-95882: Paliurus sp. showing three open germination valves, sample MRA 7-25-80-2, Henderson Bluff, Alaska. (c) GSC-95883: Paliurus type, sample FG 88-53b, Ellesmere Island. The last two specimens are similar to, but better preserved than, those seen from Prince Patrick Island. (d) GSC-95884: fragment of unknown seed, sample FG 87-2a. (e) Detail of fenestrate surface of specimen GSC-95884. (f) GSC-95885: Rhynchospora capitellata (Michx.) Vahl., sample FG 87-2A. Note: the cap typical of Rhynchospora fruits is missing on this specimen, but a scar showing its former position is evident. (g) GSC-95887: Prunus sp., sample JDB-13b. (h) GSC-95886: Myrica cf. eogale Nikit., sample FG87-10a/2. (i) GSC-95888: Lycopus sp., sample FG 87-1e).

THE PRINCE PATRICK ISLAND BIOTA

Vascular Plants

Fourteen of the sites sampled by Fyles and Devaney have been studied for fossil plants and insects. Table 1 lists vascular plants from section FG87-18, several levels of Devaney Section 1, two parts of the Green Bay section and Landing Lake site (Figures 2, 3E, 3F, 4). Many of the fossils clearly refer to extant genera, and some cannot be separated from extant species; however, a final conclusion on the specific identify of the majority of the fossils must be deferred pending more detailed comparative studies. SEM micrographs of typical plant macrofossils are shown in Figure 6, and the distribution of selected taxa in Figure 7.

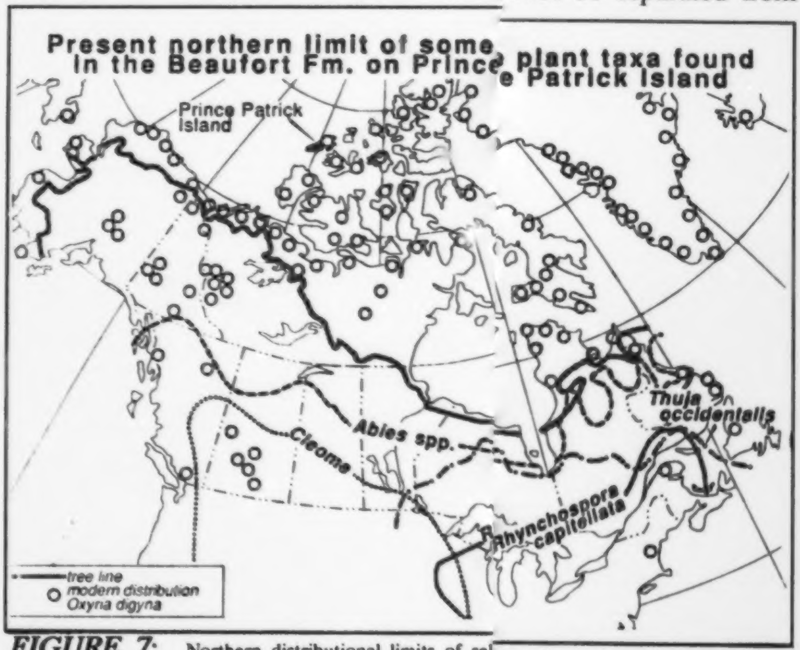

Present northern limit of some plant taxa found in the Beaufort Fm. on Prince Patrick Island
Prince Patrick Island
Abies spp.
Cleome
Thuja occidentalis
Rhynchospora capitellata
tree line
modern distribution Oxyna digyna

FIGURE 7: Northern distributional limits of selected vascular-plant taxa seen as fossils in the Beaufort Formation on Prince Patrick Island. Distribution of Abies and Thuja occidentalis after Hosie (1969); Cleome from Iltis (1957); Rhynchospora capitellata from Gale (1944); Oxyria digyna from Porsild and Cody (1980).

The samples from Devaney Section 1 contain a minimum of 64 taxa, of which approximately 11% are trees, 34% shrubs and 55% herbs. In spite of the low percentage of trees in the flora, the presence of large pieces of conifer wood (R.J. Mott, unpublished Geological Survey of Canada Palynological Report 68-4), conifer cones and abundant leaves of larch, spruce and pine (*Larix*, *Picea* and *Pinus*) indicate that the region was forested at the time of deposition. Most of the pine needles are of the five-needle white pine (*P. strobus*) type. Birch (*Betula*) nutlets are also abundant in many samples, and many are of the arboreal type. This suggests mixed coniferous/deciduous forests and a treeline at least 1,100 km north of its present position.

Supporting evidence of coniferous forests comes from preliminary pollen work by R.J. Mott (unpublished Geological Survey of Canada Palynological Report 87-11). It shows 7% spruce and 30% pine in sample 1e from Devaney Section 1. Larch pollen is rare to non-existent in the samples examined so far, but larch is often underrepresented in pollen spectra - in any case the presence of larch needles shows that the tree was growing in the region. Unlike pollen spectra from Duck Hawk Bluff on southern Banks Island, hardwood types such as hickory, walnut, elm, ash and maple (*Carya, Juglans, Ulmus, Fraxinus* and *Acer*) are missing from the Devaney Section 1 spectrum (R.J. Mott, unpublished Geological Survey of Canada Palynological Report 88-11). Hills (1975) reports a *Carya* nut from Prince Patrick Island but the location of his section and other details are not known to us. The Prince Patrick Island macrofossil assemblages discussed here lack several tree genera such as dawn redwood, China cypress, bald cypress, mulberry, tulip-tree and walnut (*Metasequoia, Glyptostrobus, Taxodium, Morus, Liriodendron* and *Juglans*) that are present in the Beaufort sediments at Duck Hawk Bluff on southern Banks Island (Figure 1).

The Prince Patrick Island pollen spectra do contain significant amounts of birch and alder (*Alnus*), which as indicated above, is matched by abundant macrofossils of these two plants. Some of the alder macrofossils are identical to fruits of *Alnus incana*, a species which currently grows near flood plains. Many of the same samples also contain coralloid actinorhizal root-nodules (Burgess and Peterson 1987) similar to those recovered from Quaternary deposits (White *et al.* 1985). They probably developed on the roots of the alders. Both arboreal and shrub-type *Betula* nutlets occur in most assemblages. One site yielded rare specimens of the large *Betula apoda*-type nutlets seen from Banks Island Beaufort Formation deposits, particularly at Duck Hawk Bluff (Matthews 1987A). They are poorly preserved and may have been rebedded from older deposits no longer exposed on the island.

Several samples contain leaves of avens (*Dryas*) and seeds indistinguishable from those of the common arctic-alpine mountain sorrel *(Oxyria digyna)* (Figure 9). FG-10a/2 also contained a few leaves of another common arctic plant, purple saxifrage *(Saxifraga oppositifolia)*. Rather than indicating an arctic environment, these fossils indicate that river floodplains in which the detritus accumulated were wide and only partly forested. This would also explain the high percentage of herbs in the flora. Many of them probably grew on the floodplains and hence were more readily incorporated in alluvial detritus than plant remains from distal forest communities.

Of the shrubs and herbs listed in Table 1, most are presently components of the northern boreal flora, but a few such as *Cleome, Decodon, Verbena, Hypericum, Sambucus, Physocarpus*, and *Wiegela* do not currently have northern representatives (Figure 7). Their presence shows that the coniferous/deciduous forests on Prince Patrick Island, though probably similar in appearance to those within the boreal zone today, were floristically unique (Matthews 1987A).

With a few exceptions, the composition of most of the Prince Patrick Island macrofossil assemblages is similar. The presence of *Betula apoda*-type fossils in one sample has already been mentioned. The lowest sample of Devaney Section 1 (6a in Figure 4) differs from the others in the sequence by the presence of a few endocarps of *Comptonia*. The organic detritus from the Landing Lake site also contains rare endocarps of *Comptonia*, but more important it is one of the few samples from Prince Patrick Island to yield fruits of the extinct lythraceous plant *Microdiptera* (Tiffney 1981). *Microdiptera* is rather common in Beaufort samples from southern Banks Island (listed as *Mneme* sp. in Matthews 1987A, 1989). Seeds of *Cleome*, a rare element in most Banks Island Beaufort samples, were present in a few of the Prince Patrick Island samples (e.g. sample 9 at Devaney Section 1 and the Landing Lake sample - Table 1). The present North American distribution of the genus is in grassland and prairie regions (Iitis 1957) (Figure 7).

Sample 11c6 at the Green Bay Section (Figure 5) is radically different from typical Beaufort floras on the island. Plant macrofossils are rare, and, unlike virtually all of the other Prince Patrick Island samples, they represent species that are now typical of northern treeline and Low-Arctic tundra sites. Even before the fossils were studied, the fact that the sediments at the Green Bay Section seem to be *inset* in the Beaufort plain suggested that they might be younger than the Beaufort Formation. The vascular plant macrofossils from sample 11c6 and bryophyte fossils (FG11c2, Table 2) from an underlying autochtonous peat support this conclusion, as do preliminary pollen analyses (R.J. Mott, unpublished Geological Survey of Canada Palynological Report 87-11). However, the vascular plant fossils from sample FG10a/2 also show clearly that the basal part of the section is of Beaufort age.

The deposits at Landing Lake are also below the level of the Beaufort plain. The autochtonous moss-mat from that section differs in its moss flora from other Beaufort deposits (see below) and may also be pre-Beaufort. But if this is so, then the Tertiary fossils in the host sediments are rebedded (see below).

Sample FG-10a/2 from the Green Bay Section contains several taxa not seen in other samples, but this may be entirely a taphonomic bias (see below). Taphonomic factors and/or inclusion of older, rebedded fossils, might explain some of the other distinctions mentioned above. It is also possible that the distinctions mean that a few of the Prince Patrick Island sites contain slightly older Beaufort sediments than the majority.

Some samples are separate from the others partly by absence of taxa seen in virtually all others. For example, FG-10a/2 (Figures 3F,5) at the Green Bay Section lacks *Abies, Pinus, Thuja, Epipremnum, Aracites*, and *Weigela* (Table 1). It also contains fossils of several plants not seen or at least rare in other samples (e.g. *Parnassia, Papaver*), unusually well preserved leaves of *Dryas*, and a few fossils of open-ground plants such as *Saxifraga oppositifolia* and *Oxyria*.

In Table 1 most of the plant fossils are only tentatively ("cf".) referred to extant species. Even those which are indistinguishable from their modern counterparts could represent extinct species. A few of the fossils, such as *Epipremnum, Paliurus, Myrica* and *Aracites* clearly represent extinct genera or species.

Fossils referred to *Epipremnum crassum* are now known to occur at a number of northern North American Neogene sites (Matthews and Ovenden, in preparation). They are not abundant or well preserved in any of the Prince Patrick Island samples, but the best are identical to well-preserved fossils of this kind from the lower part of the Ballast Brook exposure on northern Banks Island (fossils referred to *Menyanthes* by Hills (1975)). Although none of the *Epipremnum*-like fossils from the Beaufort Formation have been compared with type material, they match the description and illustrations provided by Reid and Reid (1915) for *Epipremnum crassum*, which Madison and Tiffney (1976) conclude is probably an extinct representative of the aroid subfamily Monsteroideae. Gregor and Bogner (1984) transferred *E. crassum* to the organ genus *Scindapsites*. The best preserved fossils from Prince Patrick Island also resemble illustrations and descriptions of seeds of the extant *Scindapsus officinalis* (Madison and Tiffney 1976). Both *Epipremnum* and *Scindapsus* are presently tropical to subtropical plants. The Beaufort Formation fossils show that the group of arums to which they belong formerly had a wider ecological amplitude than it does today (Matthews 1987A). *Epipremnum crassum* ranges from Oligocene to late Pliocene (Madison and Tiffney 1976) with the latest records coming from the Netherlands (Reid and Reid 1915).

Aracites fruits(?) (referred to *Aracispermum* in Matthews 1987A) are thought to represent another extinct genus of arums (Nikitin 1957). The fossils from Prince Patrick Island are identical to those shown in Plate 9.1, Figures 3 and 4 of Matthews (1987A). They are also similar to fossils originally referred to *Hippuris globosa* by Reid and Reid (1915), but subsequently assigned to *Aracites* by Nikitin (1957). Such fossils are now known from a number of late Tertiary northern North American sites (Matthews and Ovenden, in preparation) and, the genus, if not the same species, survived until the early Quaternary in Europe and North America (Aalto and Hirvas 1987; Klassen *et al.* 1988). One occurrence in an autochthonous peat from Geodetic Hills, Axel Heiberg Island is of note because it indicates the type of site where this extinct plant once grew. The peat is dominated by the mosses *Drepanocladus aduncus, Calliergon richardsonii* and *Campylium stellatum/arcticum* (L. Ovenden, unpublished Geological Survey of Canada Fossil Bryophyte Report LO-27). *Ranunculus pedatifidus* was the most abundant vascular plant with other fossils representing *Ranunculus hyperboreus, R. lapponicus, Carex aquatilis* etc. (J.V. Matthews, Jr. unpublished Geological Survey of Canada Plant Macrofossil Report 89-09). So apparently *Aracites* was a plant of wet peaty depressions such as occur commonly today in the subarctic region.

Another distinctive plant fossil occurring in several Prince Patrick Island assemblages is tentatively referred to the genus *Paliurus*. In Figures 6b and 6c we show well-preserved specimens from two other late Tertiary sites. The Prince Patrick fossils are identical but not as well preserved. The true familial and generic placement of these fossils awaits further study. Nevertheless, despite size-differences, the distinctive trilocular, three-valved fruits are similar to those referred to *Paliurus* (Rhamnaceae) by other authors (Dorofeev 1963, 1972; van Der Burgh 1987). *Paliurus* fossils are now known to occur in a number of Neogene sites in northern North America, including the 5.7 million year Lava Camp locality in western Alaska (Matthews and Ovenden, in preparation). The northernmost record is from the Strathcona Fiord region of Ellesmere Island (Figure 1) (J.V. Matthews, Jr. unpublished Geological Survey of Canada Plant Macrofossil Report 88-25; Fyles 1989).

Several Prince Patrick Island samples contain poorly-preserved fruits of *Myrica* (Figure 6g). Most specimens lack the lateral scales which are typical of *Myrica gale* and related species, but clearly belong to the subgenus *Gale*. Those retaining the lateral scales are more like the fossil species *M. eogale* (Nikitin 1976) from Siberia than to the extant *M. gale*. However, as with many of the other fossils discussed here, a definite conclusion must await comparison with type material. Fossils similar to *M. eogale* have also been found in the Kap København Formation of northern Greenland and the Beaufort Formation on Meighen Island (Bennike 1987; Matthews 1987A), and more recently from organic debris in high-level alluvium on Ellesmere Island (Fyles 1989; J.V. Matthews, Jr. unpublished Geological Survey of Canada Plant Macrofosill Report 88-24).

Bryophytes

Table 2 is a pooled list of bryophyte fossils from a number of Prince Patrick Island Sites. Two of the sites (HCA19-1c and Devaney Section 6a) contained detrital organic deposits that were of a finer facies than is typical of the Beaufort Formation. As expected of allochthonous assemblages, they contain species representing several different biotopes such as: (1) sedge-moss wetlands (*Cinclidium, Paludella squarrosa, Meesia triquetra, Catoscopium nigritum, Campylium stellatum/arcticum, Drepanocladus revolvens, Calliergon giganteum, Scorpidium scorpioides, and Tomenthypnum nitens)*; (2) drier, less organic soils (*Ditrichum flexicaule, Tortella fragillis, Rhacomitrium, Aulacomnium acuminatum, Timmia, Hypnum hamulosum, Hylocomium splendens)*; (3) stream margins (*Bryobrittonia, Philonotis, Cratoneuron filicinum, Amblystegium*); and (4) boreal forest (*Pleurozium, Sphagnum*).

In contract with the vascular plant fossils, none of the moss taxa is extinct, and moss species listed in Table 2 still occur in the Arctic today. As with the vascular plants, the epiphytic, acid-bog and forest-floor moss flora is seriously under-represented in the list. For example the feathermoss assemblage, so characteristic of modern boreal forest, is virtually absent except for rare fragments of *Pleurozium schreberi*. We attribute these deficiencies to over-representation of floodplain species, i.e. the same taphonomic bias thought to be responsible for the dominance of herbs among the vascular plants.

The other two samples listed in Table 2 were studied because they differed from typical Beaufort organic detritus by their more fibrous character, indicating that they might be autochthonous. One sample (FG11c2), from the thick fibrous peat horizon at the Green Bay Section (Figures 3(F), 5) displays horizontally-oriented moss stems forming 'felted' beds that cannot be clearly separated. It is dominated by *Drepanocladus* and *Calliergon*. Unlike the detrital assemblages, all of the identified mosses now grow in one biotope: calcareous sedge-moss wetland. Many autochthonous Low-Arctic Holocene peats are also dominated by *Drepanocladus* and *Calliergon giganteum* (L. Ovenden, unpublished data from Victoria Island, N.W.T.).

The sample from Landing Lake (Figure 2), appeared in the field to come from a tabular fragment of a moss-dominated turf layer that had slumped en masse into the river, and been buried before being disaggregated. Similar fibrous mossy "clasts" are seen in alluvial sediments of modern braided-streams in the boreal zone. The Landing Lake sample contains mosses that might all have grown on calcareous floodplain sediments. Most grow today in damp or periodically wet sites fed by calcareous seepage, which can occur in floodplain depressions or along a stream margin (*Bryum pseudotrichetrum, Paludella squarrosa* (Figure 8), *Philonotis fontana, Campylium stellatum/arcticum, Cratoneuron filicinum*, and *Tomenthypnum*). Also present are a few species of: (1) well-drained sites *(Aulacomnium acuminatum, Drepanocladus uncinatus)*; (2) disturbed areas (*Ceratodon purpureus*;) and (3) alluvium *(Thuidium abietinum)* (Steere 1978). The assemblage lacks the characteristic mosses of peaty, sedge-moss wetlands and ponds *(Sphagnum, Calliergon, Scorpidium scorpioides*, and aquatic *Drepanocladus* spp.) which are common in the other three samples.

Insects

Virtually all of the Prince Patrick Island samples examined contain insect fragments. Their preservation is more like that seen on Meighen Island than in the Beaufort Formation at Ballast Brook on Banks Island. Only half as many taxa are known from Prince Patrick Island as from Meighen Island (Matthews 1977A), but this may be a sampling bias related to the larger volume of Meighen Island sediments examined for insects.

The most diverse Prince Patrick Island fossil arthropod assemblage - much richer than the pooled Devaney Section 1 assemblage - is sample FG-10a/2 of Green Bay (Figure 5). It contains at least 45 taxa. As with the vascular plant macrofossils, we suspect the high diversity is taphonomic in origin because FG-10a/2 detritus was much finer than other samples, permitting preservation of many fragile insect fossils.

In common with Beaufort samples from Meighen and Banks island (Matthews 1977A), most Prince Patrick Island insect fossils are from beetles (Coleoptera) (Table 3). The taxa in the list represent several different biotopes, but the majority are beetles that are either

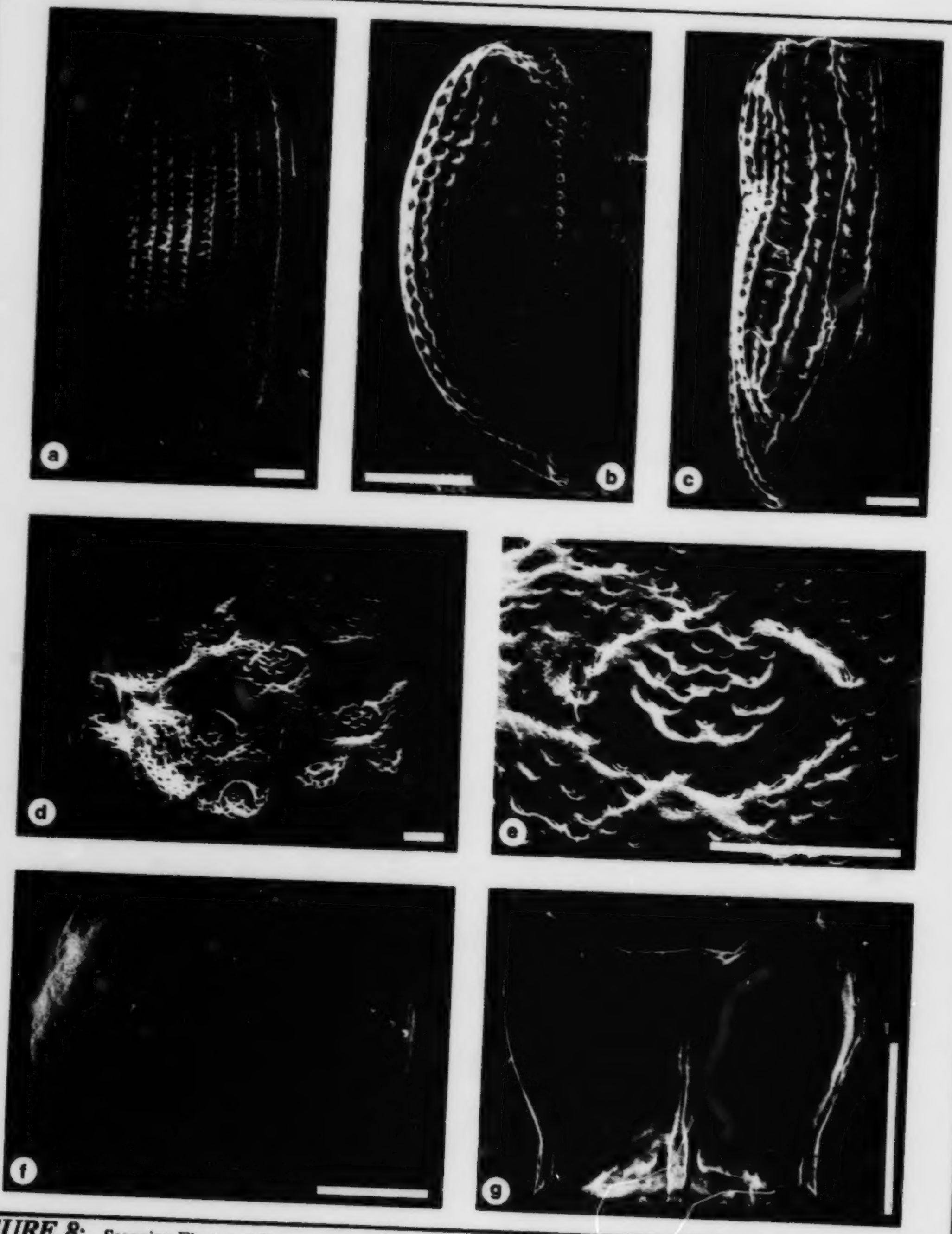


FIGURE 8: Scanning Electron Microscope images of insect fossils from the Beaufort Formation on Prince Patrick Island. Scale bar=0.3 mm. (a) GSC-95889: left elytron of a beetle: family and genus unknown, sample FG-87-1e. (b) GSC-95890: Georyssus sp., side view of right elytron, sample FG-87-1e. (c) GSC-85891: left elytron of a beetle: family and genus unknown, sample JDB-19e. This taxon is found in fossil assemblages from northern Banks Island, but has not been seen from Meighen Island. (d) GSC-95892: Elaphrus cf. E. clairvillei Kirby, fragment of left elytron, sample FG-87-18b. (e) enlargement of elytral fovae of specimen GSC-95892. (f) GSC-95893: Bembidion (Chrysobracteon) sp., pronotum, sample JDB-13b. (g) GSC-95894: Platidiolus cf. P. vandykei Kurn; pronotum, sample FG-87-10a/2.

typical of active floodplain sites near the river *(Bembidion sordidum, Bembidion (Chrysobracteon)* sp.: Figure 8f, *Nebria, Agonum bicolor, Aegialia, Morychus, Georyssus*: Figure 8b) or live in proximal wetland biotopes *(Simplocaria, Ochthebius, Helophorus, Gymnusa)*. Many of them can be found in Quaternary assemblages from the northern boreal zone. What sets Beaufort Formation assemblages apart from Quaternary samples is the presence of a few fossils of extinct species and others, such as all Pselaphidae and *Georyssus*, that now live well south of northern Canada.

DISCUSSION

Age of the Beaufort Formation on Prince Patrick Island

It is difficult to determine the age of the Beaufort Formation. It is interbedded with fossiliferous marine sediments at only one locality, Meighen Island, and to date has not yielded the types of terrestrial fossils, such as vertebrates, which ordinarily allow reference to a world-wide chronostratigraphic framework. Matthews (1977A, 1977B) has attempted to compare Beaufort insect assemblages with those from sites of known age, such as Lava Camp in western Alaska, but could suggest only that the Beaufort Formation on Meighen Island was younger than 5.7 million years old. Amino-acid ratios on mollusc shells from the Meighen Island marine unit have been interpreted to mean that associated terrestrial sediments were deposited only shortly before onset of nearly continuous cold climate (Brigham-Grette *et al.* 1987), which would mean an age no older than mid-Pliocene. Foraminiferal data (D.H. McNeil, unpublished Geological Survey of Canada Paleontology report 5) 1988) and new Sr-isotope dates in the 3 million year range (personnal communication to J.G.F. from K. Miller, 1989) show (contrary to the opinion expressed in Matthews 1989) that the Meighen Island sediments are no older than early Pliocene.

Although the above conclusions deal with Meighen Island, here we are primarily concerned with the age of the Beaufort Formation on Prince Patrick Island. The only available means of estimating that age is by comparison of plant assemblages with those from Meighen Island, other Beaufort sites and dated floras from Cook Inlet, Alaska.

Table 4, at the end of this paper, summarizes floristic data from various Beaufort localities on southern and northern Banks Island, Prince Patrick Island, Meighen Island and the 2 million year old Kap København deposits in northern Greenland (Matthews 1987A;

Bennike, in press). While it is at best a provisional template, which will undoubtedly be greatly modified as fossils from other newly discovered localities become available, the table does provide potential chronological information. For example, Prince Patrick Island macrofloras appear similar both to those from the "upper Beaufort" at Ballast Brook and Meighen Island. The similarity to Meighen Island becomes even more apparent if taxa encountered rarely at only a few of the Prince Patrick sites (see above) are removed from consideration. Remaining differences, such as the presence of seeds of *Paliurus* and *Decodon* at some Prince Patrick Island sites and not at Meighen Island might, as Hills (1975) suggested, be due to the latitudinal gradient of the time. He proposes that Prince Patrick and Meighen island floras are about the same late Miocene age (Homerian of Wolfe 1981). If they are the same age, then new data from Meighen Island (superseding information presented in Matthews 1989) showing the marine unit there was deposited about 3 million years ago, means that the Prince Patrick Island deposits discussed here may be just as young (early Late Pliocene (Clamgulchian)) rather than late Miocene.

It is highly unlikely that Prince Patrick Island deposits could be younger than those on Meighen Island, but we cannot rule out the possibility that they are older, and that the distinctions exhibited in Table 4 have both a chronological and a geographical basis. As indicated earlier, Hills (1975) reports a fossil nut of *Carya* from the island, which suggests the presence of sediments older than those discussed here, but until that single occurrence is better documented, it remains at most an intriguing curiosity.

Taphonomy

All of the macrofossils of higher plants discussed here were stream-transported before being deposited, so differential sorting and preservation have biased the assemblages (Spicer 1980, Spicer and Wolfe 1987) making it difficult to read paleoenvironmental information from them. As might be expected of fossils from alluvial detritus, many of the plants listed in Table 1 are typical of floodplain or poorly-drained spots nearby. Some in the latter class (e.g. *Menyanthes* and *Potamogeton*) produce tough seeds or fruits that float well and are easily moved by streams and deposited with alluvial sand and silt.

The unique and diverse insect and plant assemblage from sample FG-10a/2 at Green Bay (Figures 1,5) is probably the result of taphonomic bias, though the absence of key taxa seen at virtually all other sites is difficult to explain thus. Spicer (1980) has shown that organic deposits dominated by fine, well-preserved plant detritus, like FG-10a/2, are typical of certain parts of alluvial depositional systems.

Rebedding of older fossils is a special type of taphonomic bias - one which may also severely hinder the interpretation of fossil floras (Matthews *et al.* 1986; Dyke and Matthews 1987). Many samples discussed here contain fragments of amber and the distinctive needles of *Sciadopitys*, the Japanese Umbrella Pine. Both are probably derived from the Paleogene Eureka Sound Group. Could there be other less obvious rebedded fossils of late Tertiary age contaminating Prince Patrick assemblages? Fossils of the *Betula apoda* type, *Microdiptera* and *Cleome* were rare and rather poorly preserved in the Prince Patrick Island assemblages. Perhaps they are rebedded from an older unit no longer exposed on the island, and the same explanation may apply to the *Carya* fossil reported by Hills (1975).

There is no foolproof method of assessing the magnitude of the rebedded-fossil problem. All we can say is that most samples discussed here contained fossils that are similiarly preserved, hence they are assumed to be approximately contemporaneous.

Climate of Prince Patrick Island during Beaufort Time

Figure 7 shows the present distribution of some taxa to which Prince Patrick Island fossils are referred. Because many fossils probably represent extinct species, they should not be used for inferring paleoclimate (Wolfe and Tanai 1980). Comparisons based on vegetation rather than flora are a more reliable climatic indicator. For the time being, the best indication of climate on Prince Patrick Island during deposition of Beaufort sediments is the location of the region with respect to regional treeline.

Today western Prince Patrick Island, has a mean July temperature below 4°C, and is beyond the limit of woody plants (Edlund 1986; this volume). Along with Meighen Island and some of the other western QEI, it lies within the most severe climatic region in the Canadian Arctic Archipelago (Maxwell 1981). Contemporary treeline corresponds approximately with the 13°C mean July isotherm; so a forested Prince Patrick Island would have had a mean July temperature at least 9°C warmer than now.

The moss floras of North American boreal and arctic regions are much more alike than the vascular plant floras of these bioclimatic zones, making it difficult to interpret paleoclimate from a fossil assemblage of northern mosses strictly on the basis of their modern distributional limits. Nevertheless, three of the four moss assemblages in this study include species which are now extinct or very rare on the Arctic Islands (Table 1). In this group are all *Sphagnum* spp., *Diacranum leioneuron*, *Paldudella squarrosa*, *Amblystegium tenax*, and *Pleurozium schreberi* (Ireland *et al.* 1987). Most of these species occur as rare fragments in the two Beaufort detrital samples. *Paludella squarrosa* (Figure 9) is a major element of the sample from Landing Lake. Taken together, these 'boreal' mosses indicate a paleoclimate at least as warm as that of the Low-Arctic zone today.

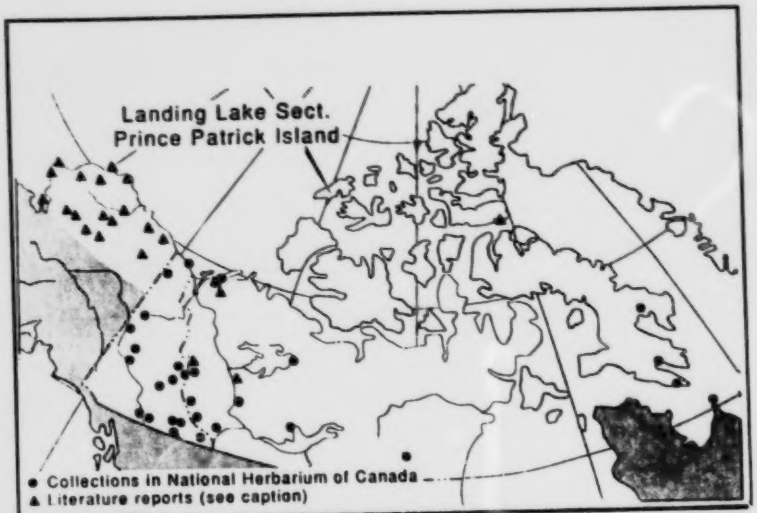

Landing Lake Sect.
Prince Patrick Island
● Collections in National Herbarium of Canada
▲ Literature reports (see caption)

FIGURE 9: **Distribution of the moss Paludella squarrosa in the Northwest Territories, Yukon Territory and Alaska north of the Arctic Circle (66°30'N). Literature records (triangles) from Steere (1978); Bird et al. (1977); Holman and Scotter (1971); and Brassard (1971).**

Paleobiogeography

In late Tertiary time Asia and North America were joined by an isthmus, and the Arctic Islands were much more a single land mass than they are now (Craig and Fyles 1960, 1965). There was ample opportunity for biotic exchange between Asia and North America - the more so because cold climate did not then impose the severe dispersal filter that it did during exposure of the Bering Isthmus in Quaternary time. Thus it is not surprising that many of the vascular plant taxa in the Prince Patrick Island assemblages appear similar to species described from east Asian and European floras (Dorofeev 1963; Nikitin 1976; Reid and Reid 1915).

The moss assemblages (Table 2) include species which belong to the circumpolar element of the Arctic moss flora. These species occur throughout the Arctic and in a few northern mountain ranges, but unlike the vascular plants, do not extend into northern hemisphere boreal and temperate zones. Steere (1965 1976) has listed species with this pattern, inferring that they are a remnant of a widespread, temperate Tertiary flora, isolated from their nearest relatives by Pleistocene glaciations. *Bryobrittonia longipes*, *Aulacomnium* *acuminatum*, *Cinclidium arcticum*, and *C. latifolium* are members of the circumpolar arctic element. Their occurrence in Tertiary fossil assemblages of distinctly boreal character from Prince Patrick Island is significant support for this phytogeographic theory.

ACKNOWLEDGEMENTS

We are grateful to Jon Devaney for his detailed notes on the stratigraphy of Devaney Section 1, allowing production of Figure 4, and for his help in collecting the samples discussed here. The Institute of Sedimentary and Petroleum Geology (Calgary) and the Polar Continental Shelf Project provided logistical support for Fyles and Devaney. J. van der Burgh (Utrecht) provided helpful advice on the identity of some problematical plant fossils, especially those of *Sciadopitys*. R.R. Ireland (National Museum of Natural Sciences) advised on the identification of many moss fragments, and D.H. Vitt (University of Alberta) confirmed the identification of *Bryobrittonia longipes*.

Alice Telka devoted much time to preparing samples and graphics for this paper, and Michelle Keir (University of Waterloo) helped isolate the fossils from many of the samples.

REFERENCES

Aalto, M.M. and H. Hirvas. 1987. *Aracites interglacialis*, a peat forming extinct plant from Finnish Lapland. Abstracts, XII INQUA Congress (Ottawa, July 1987). p. 116.

Bennike, O. 1987. News from the Plio-Pleistocene Kap København Formation, North Greenland. Polar Research 5:339-340.

______. (in press). The Kap København Formation, Plio-Pleistocene, North Greenland: sedimentology and palaeobotany. Meddelelser om Grønland, Geoscience.

Bennike, O. and J. Böcher. (in press). The Plio-Pleistocene Kap København Formation, North Greenland: plant and insect remains. Arctic.

Bird, C.D., G.W. Scotter, W.C. Steere, and A.H. Marsh. 1977. Bryophytes from the area drained by the Peel and Mackenzie rivers, Yukon and Northwest Territories, Canada. Canadian Journal of Botany 55:2879-2918.

Brassard, G.R. 1971. The mosses of northern Ellesmere Island. I. Ecology and phytogeography, with an analysis for the Queen Elizabeth Islands. Bryologist 74:233-281.

Brigham-Grette, J., J.V. Matthews Jr., and L. Marincovich Jr. 1987. Age and paleoenvironmental significance of Arctica in the Neogene Beaufort Formation on Meighen Island, Queen Elizabeth Islands, Canada. Abstracts, 16th Arctic Workshop (Research on the Roof of the World). University of Alberta, Edmonton. Boreal Institute for Northern Studies. pp. 12-14.

Burgess, D. and R.L. Peterson. 1987. Effect of nutrient conditions on root nodule development in *Alnus japonica*. Canadian Journal of Botany 65(8):1658-1670.

Craig, B.G. and J.G. Fyles. 1960. Pleistocene geology of Arctic Canada. Geological Survey of Canada, Paper 60-10:1-21.

______. 1965. Quaternary of Arctic Canada. In: Anthropogene Period in Arctic and Subarctic. Institute of the Geology of the Arctic, State Geological Committee, U.S.S.R., Moscow. Transactions of Scientific Research 143. pp. 5-33. (In Russian).

Devaney, J.R. and J.G. Fyles. 1988. Sedimentology and stratigraphy of the Beaufort Formation, Prince Patrick Island, N.W.T. Joint Annual Meeting GAC, MAC, OSPG, Memorial University of Newfoundland (St. John's Newfoundland, May 23-25). Program and Abstracts. p. 31.

Dorofeev, P.I. 1963. Tertiary floras of western Siberia. U.S.S.R. Academy of Sciences, Komorov Botanical Institute. 345 pp. (In Russian).

______. 1972. Treticnye flory Bassejna r. Omoloja. In: Istorija flory i rastitel'nosti Eurazii. Nauka, Leningrad. pp. 41-112.

Dyke, A.S. and J.V. Matthews Jr. 1987. Stratigraphy and paleoecology of Quaternary sediments along Pasley River, Boothia Peninsula, central Canadian Arctic. Géographie physique et Quaternaire 41(3):323-344.

Edlund, S.A. 1986. Modern arctic vegetation distribution and its congruence with summer climate patterns. In: Climate Change Impacts in the Canadian Arctic. Edited by: H.M. French. Proceedings of a Canadian Climate Program workshop (March 3-5, 1986). pp. 84-99.

Fyles, J.G. 1987. Stratigraphy of the Beaufort Formation as seen from Prince Patrick Island. Workshop on Neogene Environments around the Arctic Basin (Denver, Colorado). Unpublished abstract.

______. 1989. High terrace sediments, probably of Neogene age, west central Ellesmere Island, Northwest Territories. Geological Survey of Canada, Paper 89-1D:101-104.

Gale, S. 1944. *Rhynchospora*, section *Eurhynchospora*, in Canada, the United States and the West Indies. Rhodora 46:90-134, 159-197, 207-249, 259-278.

Gregor, H.J. and J. Bogner. 1984. Fossile Araceen Mitteleuropas und ihre rezenten Vergleichsformen. Documenta Naturae 19:1-12.

Hills, L.V. 1975. Late Tertiary floras of Arctic Canada: an interpretation. Proceedings of Circumpolar Conference on Northern Ecology. National Research Council of Canada, Ottawa. pp. I(65)-I(71).

Hills, L.V., J.E. Klovan, and A.R. Sweet. 1974. *Juglans eocinerea* n.sp., Beaufort Formation (Tertiary) southwestern Banks Island, Arctic Canada. Canadian Journal of Botany 52:65-90.

Hills, L.V. and J.V. Matthews, Jr. 1974. A preliminary list of fossil plants from the Beaufort Formation, Meighen Island. Geological Survey of Canada, Paper 74-1B:224-226.

Holman, K. and G.W. Scotter. 1971. Mosses of the Reindeer Preserve, Northwest Territories, Canada. Lindbergia 1-2:34-56.

Hopkins, D.M., J.A. Wolfe, J.V. Matthews, Jr., and M.L. Silberman. 1971. A Pliocene flora and insect fauna from the Bering Strait region. Palaeogeography, Palaeoclimatology, Palaeoecology 9:211-231.

Hosie, R.C. 1969. Native trees of Canada. Seventh Edition. Canadian Forestry Service, Ottawa. 380 pp.

Iltis, H.H. 1957. Studies in the Capparidaceae. III. Evolution and phylogeny of the western North American Cleomoideae. Annals of the Missouri Botanical Garden 44:77-119.

Ireland, R.R., G.R. Brassard, W.B. Schofield, and D.H. Vitt. 1987. Checklist of the mosses of Canada II. Lindbergia 13:1-62.

Kuc, M. 1973. Fossil flora of the Beaufort Formation, Meighen Island, N.W.T., Canada. Era. Canadian-Polish Research Institute, Series A, No. 1:1-44.

Kuc, M. and L.V. Hills. 1971. Fossil mosses, Beaufort Formation (Tertiary), northwestern Banks Island, western Canadian Arctic. Canadian Journal of Botany 49:1089-1094.

Madison, M. and B.H. Tiffney. 1976. The seeds of the Monsteridae: their morphology and fossil record. Journal of the Arnold Arboretum 57:185-201.

Matthews, J.V., Jr. 1977A. Tertiary Coleoptera fossils from the North American Arctic. Coleopterists Bulletin 31(4):297-308.

Matthews, J.V., Jr.. 1977B. Coleoptera fossils: their possible value for dating and correlation of late Cenozoic sediments. Canadian Journal of Earth Sciences 14:2339-2347.

______. 1987A. Plant macrofossils from the Neogene Beaufort Formation on Banks and Meighen Islands, District of Franklin. Geological Survey of Canada, Paper 87-1A:73-87.

______. 1987B. Plant and insect fossils from Beaufort Formation and related Neogene deposits in Yukon and Alaska: unfinished business; new business. Workshop on Neogene environments around the Arctic Basin (Denver, Colorado). Unpublished abstract.

______. 1989. New information on the flora and age of the Beaufort Formation, Arctic Archipelago, and related Tertiary deposits in Alaska. Geological Survey of Canada Paper 89-1D:105-111.

Matthews, J.V., Jr., R.J. Mott, and J.-S. Vincent. 1986. Preglacial and interglacial environments of Banks Island: pollen and macrofossils from Duck Hawk Bluffs and related sites. Géographie physique et Quaternaire 40:279-298.

Matthews, J.V., Jr. and L.O. Ovenden. (in preparation). Late Tertiary plant and insect macrofossil localities in northern North America (Alaska, Yukon and Northwest Territories): a review of available data.

Maxwell, J.B. 1981. Climatic regions of the Canadian Arctic islands. Arctic 34:225-240.

Nikitin, P.A. 1957. Pliocenovye i cetverticnye flory Voronezskoj Oblasti. Akademia nauk SSSR, Moscow. 200 pp.

Nikitin, V.P. 1976. Flora Mamontovoj gory po semenam i plodam. In: Miocen Mamontovoj Gory. Edited by: V.N. Saks. Nauka, Moscow. pp. 131-194.

Porsild, A.E. and W.J. Cody. 1980. Vascular plants of continental Northwest Territories, Canada. National Museums of Canada, Ottawa. 667 pp.

Reid, C. and E.M. Reid. 1915. The Pliocene floras of the Dutch-Prussian border. Mededeelingen van de Rijksopsporing van Delfstoffen No. 6:1-178.

Spicer, R.A. 1980. The importance of depositional sorting to the biostratigraphy of plant macrofossils. In: Biostratigraphy of Fossil Plants: Successional and Paleoecological Analyses. Edited by: D.L. Dilcher and T.N. Taylor. Dowden, Hutchinson and Ross, Stroudsburg. pp. 171-183.

Spicer, R.A. and J.A. Wolfe. 1987. Plant taphonomy of the late Holocene deposits in Trinity (Clair Engle) Lake, northern California. Paleobiology 13(2):227-245.

Steere, W.C. 1965. The boreal bryophyte flora as affected by Quaternary glaciation. In: The Quaternary of the United States. Edited by: H.E. Wright Jr, and D.G. Frey. Princeton University Press, Princeton. pp. 485-495.

______. 1976. Ecology, phytogeography and floristics of arctic Alaskan bryophytes. Journal of the Hattori Botanical Laboratory 41:47-72.

______. 1978. The mosses of arctic Alaska. J. Cramer Vaduz. 508 pp.

Tiffney, B.H. 1981. Fruits and seeds of the Brandon lignite. VI. *Microdiptera* (Lythraceae). Journal of the Arnold Arboretum 62:487-516.

Tozer, E.T. 1956. Geological reconnaissance of Prince Patrick, Eglinton and western Melville Islands, Arctic Archipelago, Northwest Territories. Geological Survey of Canada, Paper 55-5:21-32.

van Der Burgh, J. 1987. Miocene floras in the lower Rhenish Basin and their ecological interpretation. Review of Palaeobotany and Palynology 52:299-366.

White, J.M., R.W. Mathewes, and W.H. Mathews. 1985. Late Pleistocene chronology and environment of the "ice-free corridor" of northwestern Alberta. Quaternary Research 24:173-186.

Wolfe, J.A. 1981. A chronologic framework for Cenozoic megafossil floras of northwestern North America and its relation to marine geochronology. Geological Society of America, Special Paper 184:39-47.

Wolfe, J.A. and T. Tanai. 1980. The Miocene Seldovia Point flora from the Kenai Group, Alaska. United States Geological Survey, Professional Paper 1105:1-52.

Illustrated by Brenda Carter

TABLE I: PLANT MACROFOSSILS FROM SELECTED SITES ON PRINCE PATRICK ISLAND.

	^{b}FG18	^{c}Devaney Sect. 1							^{c}Green Bay		Landing Lk.
		6a	9	2	13&1e	11	14	2a	10a/2	11c6	
Amber	+	+			+	+		+	+	+	+
MYCOPHYTA											
Actinorhizal nodules	+	+	+								
PHYCOPHYTA											
Characeae											
Chara/Nitella								+	+		
BRYOPHYTA		+	+		+	+	+	+	+	+**	+**
PTERIDOPHYTA											
Selaginellaceae											
Selaginella sp.				+		+	+		+		
SPERMATOPHYTA											
Pinaceae											
Abies sp.	+			+	+	+	+	+			+
Larix sp.	+		+	+	+	+	+	+	+		+
Pinus sp.	+		+		+	+		+			+
Pinus strobus type			+								
Picea sp.	+				+	+	+		+	+	+
Taxodiaceae											
Metasequoia sp.†	+										
Cupressaceae											
Thuja occidentalis L.	cf.		cf.	cf.				cf.			
Sparganiaceae											
• *Sparganium* sp.	+	+							+		
• *S. hyperboreum* Laest.							+				
Potamogetonaceae											
• *Potamogeton* spp.	+		+	+	+		+		+		+
Alismaceae											
• *Sagittaria* sp.	?	+			?						+
Gramineae											
Genus sp.					+			+	+		
• *Glyceria* sp.	?										
Cyperaceae											
Carex spp.	+	+		+	+	+		+	+	+	+
• *C.* sect. *acutae*			+								
• *Eleocharis* sp	+				+		?				
• *E. palustris/uniglumis* type								+			
• *Rhynchospora* *capitellata* (Michx.)Vahl.									+		
• *Scirpus* sp..			+	+	+		+	?	+		
• *S. validus* type									+		
Araceae											
Epipremnum *crassum* Reid&Reid††		+	+	+			+				
Aracites sp.	+		+	+	+		+				
Juncaceae											
• *Juncus* spp.									+		
• *Luzula* sp.							?				
Salicaceae											
Populus sp.					+						
• *Salix* sp.	+		+	+	+				+		+
Myricaceae											
Myrica eogale Nikit.††	cf.	?	?	cf.	cf.		cf.		cf.		
Comptonia sp.		+									?

TABLE 1: (cont.)

	[b]FG18	[c]Devaney Sect. 1							[c]Green Bay		Landing Lk.
		6a	9	2	13&1e	11	14	2a	10a/2	11c6	
Betulaceae											
Alnus sp.			+		+				+		+
A. crispa (Alt.)Pursh	+	+	+						+		
• *A. incana* (L.)Moench	+		+	+		+			+		+
Betula dwarf shrub	+				+			+	+	+	
Betula arboreal type	+			+	+	+			+		+
Betula apoda Nikit.††	cf.										?
Tubela sp.††	cf.										
Polygonaceae											
Oxyria digyna (L.)Hill	+			+			+	+	+		
• *Polygonum* sp.			+								
• *Rumex* sp.	+		+	+	+	+	+	+	+		?
Chenopodiaceae											
• *Chenopodium* sp	+		+		+	+			+		
Portulacaceae											
Claytonia sp.									+		
Caryophyllaceae											
Genus?			+								
Melandrium sp									+		
Silene sp									+		
Nymphaeaceae											
• *Nuphar* sp.		+			+						
Ranunculaceae											
Ranunculus sp.					+			+	+		
• *R. hyperboreus* Rottb.		cf.	cf.			cf.		cf.			cf.
• *R. sceleratus* type				?							
R. pensylvanicus L.f.	cf.										
R. lapponicus L.		cf.							cf.	+	cf.
Thalictrum sp.	+				+			+			+
Papaveraceae											
Papaver sp.								+	+		
Capparidaceae											
Cleome sp.				+							+
Cruciferae											
• *Rorippa* sp.								+	+		
Draba sp.									+		
Saxifragaceae											
• *Parnassia* sp.									+		
Saxifraga sp.											?
S. oppositifolia L.									+		
Rosaceae											
Dryas sp.					+		?	+			+
Physocarpus sp.	+		+	+	+						+
Potentilla sp.				+		+	+	+	+	+	
• *P. palustris* (L.)Scop.	cf.						cf.				
P. norvegica L.	cf.	cf.		cf.					cf.		
• *P. anserina* L.									cf.		
Prunus sp.	+		+		+						
P. Maximowiczii Ruprecht.				cf.							
Rubus idaeus L.	cf.								cf.		
Rubus sp.		+	+			+					
Fragaria									cf.		
Rhamnaceae											
Paliurus sp.		+	+								+
Hypericaceae											
• *Hypericum* sp.	+					+		+	+		
Violaceae .											
Viola sp.	+	+		+					+		
Lythraceae											
• *Decodon* sp.	+	+	+	+	+	+	+	+	+		+
Microdiptera sp.††											+

TABLE 1: *(cont.)*

	[b]FG18	[c]Devaney Sect. 1							[c]Green Bay		Landing Lk.
		6a	9	2	13&1e	11	14	2a	10a/2	11c6	
Haloragaceae											
• *Hippuris* sp.	+	+	+	+	+		+	+	+		+
• *Myriophyllum* sp.											
• *M. exalbescens* Fern.								cf.			
Araliaceae											
Aralia sp.											+
Umbelliferae											
Genus?									+		
Ericaceae											
Vaccinium vitis-idaea L.										cf.	
Empetrum sp.			+	+			+		+		
Andromeda sp.	+	+	+	+		+			+		
Vaccinium sp.						+				+	
Chamaedaphne sp.	+		+		+	+			+		
Cornaceae											
Cornus sp.		+									
• *C. stolonifera* Michx.	cf.			cf.	cf.						cf.
Primulaceae											
Primula sp.									?		
Gentianaceae											
• *Menyanthes trifoliata* L.	+	+	+	+	+			+	+	+	
Menyanthes (<2mm)††	+	+			+					+	
Verbenaceae											
• *Verbena* sp.	+		+			+		+	+		
Labiatae											
• *Lycopus* sp.				+	+				+		
• *Teucrium* sp.			+								
Caprifoliaceae											
Sambucus sp.	+	+			+	+	+				+
Weigela sp.†				+	+	+					
Compositae undet.								+			

[a] For location of sites see Figure 2. Stratigraphic position of samples from Devaney Sect. 1 and the Green Bay Section are shown in Figures 4 and 5 respectively.

b. FG18 = Site FG87-18 (Fig. 2) and pooled samples FG87-18 a,b abd c from the top middle and bottom on one 1m silt horizon.

[c] Only numbers are given for column heading, i.e., 9= JD89, 1e=FG1e etc. Plants from samples FG1e and JD813 are pooled because they both represent about the same stratigraphic horizon.

[d] Landing Lake = Devaney Section 8. The list is a combination of taxa in two samples: JD848 and FG87-31a.

• indicates those taxa that now grow on floodplains or occur nearby and are readily incorporated into alluvial sediments.

~ indicates samples from which Bryophytes have been examined by Ovenden (this paper)

† = Extinct in North America

†† = Extinct throughout the world

TABLE 2: BRYOPHYTE TAXA FROM THE BEAUFORT FORMATION AND RELATED UNITS ON PRINCE PATRICK ISLAND..

	Beaufort Detrital Samples[1]	**Landing Lake**	**Green Bay (FG11c2)**
Sphagnaceae			
Sphagnum sect. *Sphagnum*	◆		
S. teres (Schimp.)Aongstr. ex C.Hartm.	◆		
S. sect. *Subsecunda*	◆		
S. sect. *Acutifolia*	◆		
Ditrichaceae			
Ditrichum flexicaule (Schwaegr.)Hampe	◆		
Distichium capillaceum (Hedw.)B.S.G.	◆	◆	
Ceratodon purpureus (Hedw.)Brid.		◆	
Dicranaceae	◆		
Dicranum sp.			◆
Encalyptaceae			
Bryobrittonia longipes (Mitt.)Horton	◆		
Pottiaceae			
Tortella fragilis(Drumm.)Limpr.	◆		
Grimmiaceae			
Rhacomitrium sp.	◆		
Schistidium apocarpum ?	cf.		
Bryaceae			
Pohlia sp.	◆		
Bryum spp.	◆	◆	◆
Mniaceae			
Mnium marginatum(With.)Brid. ex P. Beauv.	cf.		
Cinclidium arcticum(B.S.G.)Schimp.	◆		
Cinclidium latifolium Lindb.	◆	◆	cf.
Cinclidium sp		◆	
Aulacomniaceae			
Aulacomnium palustre(Hedw.)Schwaegr.	◆		
A. acuminatum(Lindb.&H.Arnell)Kindb.	◆	◆	
A. turgidum(Wahlenb.)Schwaegr			◆
Meesiaceae			
Paludella squarrosa(Hedw.)Brid.	◆	◆	
Meesia triquetra(Richt.)Aongstr.	◆	◆	◆
M. longiseta Hedw	◆	◆	
Bartramiaceae			
Philonotis fontana (Hedw.)Brid.	◆	◆	
Timmiaceae			
Timmia sp.	◆	◆	
Thuidiaceae			
Thuidium abietinum (Hedw.)B.S.G.		◆	

TABLE 2: (cont.)

	HCA19-1c & Devaney 5a	Landing Lake	Green Bay (FG11c2)
Amblystegiaceae			
Cratoneuron filicinum (Hedw.)Spruce	+	+	
Amblystegium riparium (Hedw.)B.S.G.	cf.		
A. tenax (Hedw.)C.Jens.	cf.		
Campylium stellatum/arcticum (Williams)Broth.	+	+	+
C. polygonum (B.S.G.)C.Jens.	+		
Drepanocladus revolvens (SW.)Warnst.	+		
D. exannulatus (B.S.G.)Warnst.	+		
D. fluitans (Hedw.)Warnst.	+		
D. pseudostramineus (C.Müll.)Roth	+		
D. tundrae (H.Arnell)Loeske	+		
D. aduncus (Hedw.)Warnst.	+		+
D. uncinatus (Hedw.)Warnst.	+	+	
Calliergon giganteum (Schimp.)Kindb.	+		+
Scorpidium scorpioides (Hedw.)Limpr.	+		+
Brachytheciaceae			
Tomenthypnum nitens (Hedw.)Loeske	+	+	
Brachythecium turgidum (C.J. Hartm.)Kindb..	cf.		
Hypnaceae			
Orthothecium chryseum (Schwaegr. ex Schultes)B.S.G.			+
Hypnum hamulosum B.S.G.	+		
Hypnum sp.	+		
Hylocomiaceae			
Pleurozium schreberi (Brid.)Mitt.	+		
Hylocomium splendens (Hedw.)B.S.G.	+		
Polytrichaceae			
Polytrichum alpinum Hedw.	cf.		

1. Samples include FG-1a, FG-2a, HCA19-1c and FG-17d (from Devaney Sect. 6a)

TABLE 3: PRELIMINARY LIST OF INSECT AND OTHER ANIMAL FOSSILS FROM THE BEAUFORT FORMATION, PRINCE PATRICK ISLAND..

	[a]FG18	[b]Devaney Section 1	[c]GreenBay FG10a/2
PORIFERA			
Haplosclerina			
Spongillidae			
Spongilla type			+
BRYOZOA			
Cristatella mucedo L.	+	+	
ARTHROPODA			
INSECTA			
Odonata		+	
Homoptera			
Cicadellidae			
Genus?	+		+
Coleoptera			
Carabidae			
• *Trachypachus* sp.	+	+	
Carabus sp.		+	
Carabus (*Hemicarabus*) sp.	+		
• *Nebria* sp.	+	+	
• *Notiophilus* sp.	+	+	
Diacheila polita Fald.	cf.	cf.	
Diacheila sp.	+	+	
Blethisa multipunctata L.		cf.	
Elaphrus clairvillei Kby.	cf.		
• *Elaphrus* sp.		+	+
Loricera sp.		+	
Dyschirius sp.	+	+	+
D. tridentatus grp.		+	
• *Platidiolus vandykei* Kurn.			cf.
Trechus sp.		+	
• *Asaphidion yukonense* Wick.			cf.
• *Asaphidion alaskanum* Wick.	cf.	cf.	
• *Bembidion* (*Chrysobracteon*) sp.	+	+	
• *Bembidion dyschirinum* LeC.		cf.	
Bembidion quadrimaculatum L.			cf.
• *Bembidion sordidum* Kby.			+
Bembidion(*Trepanedoris*) sp.			+
Pterostichus sp.	+		
Pterostichus(*Cryobius*) spp.	+	+	
Pterostichus vermiculosus Men.	cf.	cf.	
• *Agonum bicolor* Dej.		cf.	
Amara sp.		+	
Amara (*Curtinotus*) sp.	+		
Dytiscidae			
Genus?	+	+	
Hygrotus sp.		+	
Colymbetes sp.			+
Hydrophilidae			
Helophorus sp.	+	+	+
Helophorus (*Cyphelophorus*) sp.			+

TABLE 3: (cont.)

		FG18	Devaney Section 1	Green Bay FG10a/2
	Hydraenidae			
	Ochthebius sp.			+
	Georyssidae			
•	*Georyssus* sp.		+	
	Staphylinidae			
	Micropeplus sculptus LeC.		+	
	Micropeplus cribratus LeC.		+	
	Kalissus nitidus LeC.		cf.	
•	*Bledius* sp.	+	+	+
	Olophrum sp.			+
	Acidota sp.		+	
	Micralymma type			+
	Stenus sp.	+	+	+
	Tachinus sp.		+	+
	Aleocharinae	+		+
	Gymnusa sp.	+		+
	Pselaphidae			
	Genus?			+
	Silphidae			
	Silpha sp.	+	+	
	Scarabaeidae			
•	*Aegialia* sp.	+	+	+
	Byrrhidae			
	Curimopsis sp.	+		
	Simplocaria sp	+	+	+
•	*Morychus* sp.		+	+
	Cytilus alternatus type		+	+
	Heteroceridae			
	Heterocerus sp.	+		
	Elateridae			
	Genus?			+
	Anobiidae			
	Genus?			+
	Coccinellidae			
	Genus?			+
	Nephus sp.			+
	Lathridiidae			
	Genus?	+		+
	Chrysomelidae			
	Donaciinae	+	+	+
	Chrysomela sp.			+
	Curculionidae			
	Phyllobius sp.		?	
	Vitavitus sp.	+		+
	Lepyrus sp.	+		
•	*Lepidophorus* sp.	?		
	Notaris sp.		?	
	Pissodes sp.		+	
•	*Grypidius* sp.		+	
	Scolytidae			
	Several genera			

TABLE 3: (cont.)

	FG18	Devaney Section 1	Green Bay FG10a/2
Diptera			
Tipulidae			
Tipula sp.			+
Chironomidae			
Genus?			+
Xylophagidae			
Xylophagus sp.	+		+
Hymenoptera			
Symphyta			+
Ichneumonoidea			+
Diapriidae		+	
Formicidae	+		
CRUSTACEA			
Daphnia sp.			+
ARACHNIDA			
Acari			
Oribatei	+	+	
Cepheus type			+

a. FG18 = Site FG87-18 (Fig. 2) and pooled samples FG87-18 a,b abd c from the top middle and bottom on one 1m silt horizon.

b. Devaney Sect. 1= all fossils identified to date from the numerous samples from this section. Sample FG87-1e (Fig. 4) was one that had an abundance of insect fossils.

c. Green Bay, FG10a/2=Green Bay section, lowest Beaufort sample (see Fig. 5).

* Identifies taxa which are most often collected in stream-side communities.

TABLE 4: COMPARISON OF DISTRIBUTION WITHIN BEAUFORT FORMATION AND AT KAP KØBENHAVN (GREENLAND) OF SELECTED PLANT TAXA[a].

Taxon	Banks Is. DHB	Banks Is. L	Banks Is. U	Prince Pat.Is.	Meighen Is.	K.København Greenland
Phyllanthus sp.	+					
Actinidia sp.†	+					
Liriodendron sp.	+					
Metasequoia sp.†	+					
Tsuga sp.	+					
Taxodium sp.	+					
Glyptostrobus sp.†	?	+				
Cleome sp.†	+		+	+*		
Betula apoda type†	+		+	+*		
Epipremnum crassum †	+	+	+	+		
Microdiptera sp.†	+		+	+*		
Weigela sp.†	+			+		
Paliurus sp.	+			+		
Decodon sp.	+		+	+		
Abies sp.	+[b]		?	+		
Verbena sp.			?	+		
Comptonia sp.†	+		+	+	+	
Pinus (5 needle type)	+	+	+	+	+	
Myrica gale type†		+	+	+	+	+
Picea sp.	+	+	+	+	+	+
Larix sp.	+	+	+	+	+	+
Thuja ocidentalis	cf.			+	+	+
Oxyria digyna				+	+	+
Menyanthes trifoliata		+	+	+	+	+
Betula dwarf shrub type			+	+	+	+
Saxifraga oppositifolia					+	
Viburnum edule						+

a. Banks Island-L. = lower Beaufort Formation at Ballast Brook; Banks Island-DHB=Beaufort Formation at Duck Hawk Bluffs (Matthews, 1989); Banks Island-U=Upper Beaufort Formation at Ballast Brook; Prince Pat.=Pooled Prince Patrick Beaufort localities; Meighen Is.=pooled samples from several sites on Meighen Island (Matthews, 1987a); K.København, Greenland=Kap København site, northern Greenland (from Bennike and Böcher, in press and pers. comm., 1988).

b. *Abies* fossils from Duck Hawk Bluffs represent a species near *A. grandis*, while those from Prince Patrick Island refer to another species.

* indicates taxa which occur rarely in only a few Prince Patrick samples.

ICE AGE VERTEBRATES IN THE CANADIAN ARCTIC ISLANDS

C.R. Harington[1]

Abstract: Remains of Pleistocene (about 2 million to 10,000 years ago) vertebrates are rarely found in the Canadian Arctic Islands. From earliest to latest they include: a few fossils of middle Pleistocene interglacial (perhaps 700,000 years old) tundra-adapted animals from southern Banks Island; small seal, large whale, small horse and bison from last interglacial (or earlier) deposits near the Beaufort Sea coast; a mammoth and tundra muskox of possible early Wisconsin age from Garry Island in the same region; a middle Wisconsin Dovekie from southern Ellesmere Island and a tundra muskox of that age (or older) from Banks Island; as well as several species (e.g. mammoth, small horse, saiga antelope and tundra muskox) from late Wisconsin deposits of the western islands (Melville, Banks, Baillie and Herschel).

Early Holocene (about 10,000 to 5,000 years ago) vertebrates from the Arctic Islands are more commonly found and include: Oldsquaw duck, ringed seal, walrus, narwhal, bowhead whale, Peary caribou and tundra muskox. Many Holocene mammal (mainly marine mammal) remains have been collected from raised beaches in the archipelago during the past decade. Radiocarbon dates on these specimens indicate relatively warm (open water) conditions about 9,000 and 4,000 years ago.

Résumé: Les vestiges de vertébrés du Pléistocène (il y a environ 2 millions à 10,000 ans) ne se retrouvent que rarement dans les îles de l'Arctique canadien. Ils comprennent les vestiges de: quelques animaux fossiles adaptés à la toundra, dans le sud de l'île Banks, datant de l'époque interglaciaire du Pléistocène moyen, (il y a probablement 700,000 ans); grosse baleine, petit phoque, petit cheval et petit bison près de la côte de la mer de Beaufort, datant du dernier interglaciaire (ou plus récent); mammouth dans l'île Garry dans la même région, possiblement de la période inférieure du Wisconsinien; mergule nain dans le sud de l'île Ellesmere, datant du Wisconsinien moyen, et boeuf musqué de la toundra de l'île Banks, du même âge ou plus vieux; également plusieurs espèces datant du Wisconsinien supérieur, par exemple, mammouth, petit cheval, antilope saïga et boeuf musqué de la toundra.

Les espèces retrouvées dans les îles de l'Arctique canadien datant de l'Holocène inférieur comprennent: le canard kakawi, le phoque annelé, le morse, le narval, la baleine boréale (en grand nombre), le caribou de Peary et le boeuf musqué de la toundra. Des vestiges de plus en plus nombreux de mammifères, surtout marins, datant de l'Holocène, découverts sur les plages surélevées de l'archipel permettent de croire à un repeuplement accéléré des endroits couverts de glace lors de la dernière glaciation.

INTRODUCTION

This paper focuses mainly on vertebrates other than marine mammals, and on Pleistocene and early Holocene finds (Figure 1). Data on specimens (Table 1, at the end of this paper) usually include: identification, skeletal part, catalogue number, locality, collector(s), year of collection, radiocarbon dates, pertinent stratigraphy and references. Many of the specimens are in the Quaternary Zoology Collection of the National Museum of Natural Sciences (NMC) in Ottawa.

Of nearly 60 specimens dealt with, about a third are from Herschel Island in the Yukon Territory which, with islands near the mouth of the Mackenzie Delta and Baillie Islands, I consider to be part of the Canadian Arctic Islands. Specimens include approximately 17 genera, at least three of which represent birds.

---

[1] Paleobiology Division, National Museum of Natural Sciences, Ottawa, Ontario K1P 6P4

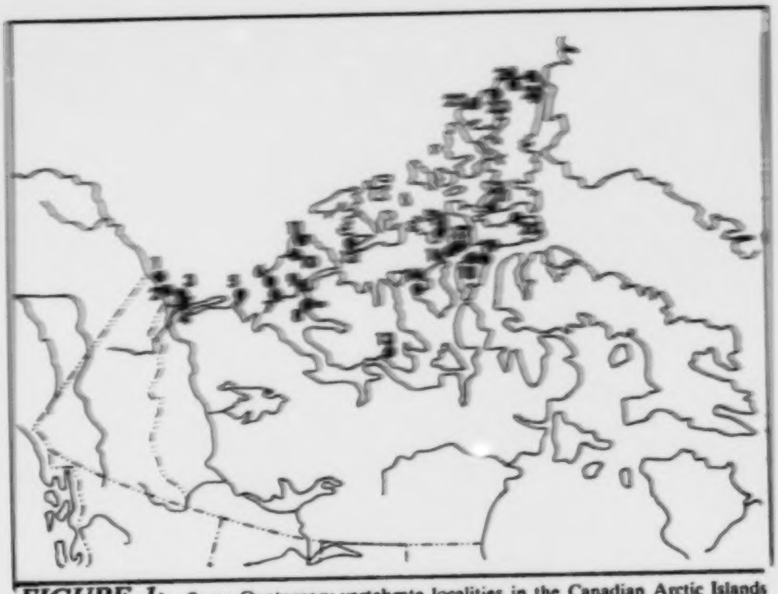


FIGURE 1: Some Quaternary vertebrate localities in the Canadian Arctic Islands that are mentioned in the text. Key: 1. Herschel Island, Y.T. 2. Mackenzie Bay ("Immerk") 3. Garry Island 4. Richards and Summer islands 5. Baillie Islands 6. Duck Hawk Bluff, Banks Island 7. Masik River, Banks Island 8. Cape Wollaston, Victoria Island 9. Jesse Bay, Banks Island 10. Bernard River, Banks Island 11. Ballast Brook, Banks Island 12. Cape James Ross, Melville Island 13. Ferguson Lake, Victoria Island 14. Cape Richard Collinson, Prince of Wales Island 15. Goodsir Inlet - Muskox River area, Bathurst Island 16. Griffith Island 17. Resolute area, Cornwallis Island 18. Cunningham River, Somerset Island 19. Northeast coast, Somerset Island 20. Truelove Inlet, Devon Island 21. Cape Storm, Ellesmere Island 22. Cape Woods, Ellesmere Island 23. Thores River, Ellesmere Island 24. Clements Markham Inlet - Piper Pass area, Ellesmere Island 25. Alert, Ellesmere Island.

The earliest finds were made by members of expeditions exploring the islands (e.g. Nares' Royal Navy expedition to northern Ellesmere Island (1875-1876) (Figure 2), and the Canadian Arctic Expedition (1913-1918)). However, most finds have been made during the last 30 years by Quaternary geologists during the course of extensive field programs. Generally, sites have not proved sufficiently productive to warrant excavation by paleontologists. Nevertheless, it seems advisable to look carefully at the possibility of recovering Pleistocene vertebrate remains in the western Arctic Islands - particularly Banks and Herschel islands.

PLEISTOCENE VERTEBRATES

The earliest reports involve lemming (*Dicrostonyx torquatus*) and ptarmigan (?*Lagopus* sp.), as well as an unidentified medium-sized mammal from interglacial deposits perhaps 700,000 years old on southern Banks Island. Paleoenvironmental data from deposits at Jesse Bay suggest a tundra-like landscape that was warmer than present (Miller 1985).

Remains of small seal (*Phoca* sp.), a large whale like the bowhead (cf. *Balaena mysticetus*), small horse (*Equus lambei*) and bison (*Bison* sp.) were derived from last interglacial (or earlier) deposits on or near islands off the Beaufort Sea coast (e.g. Herschel,

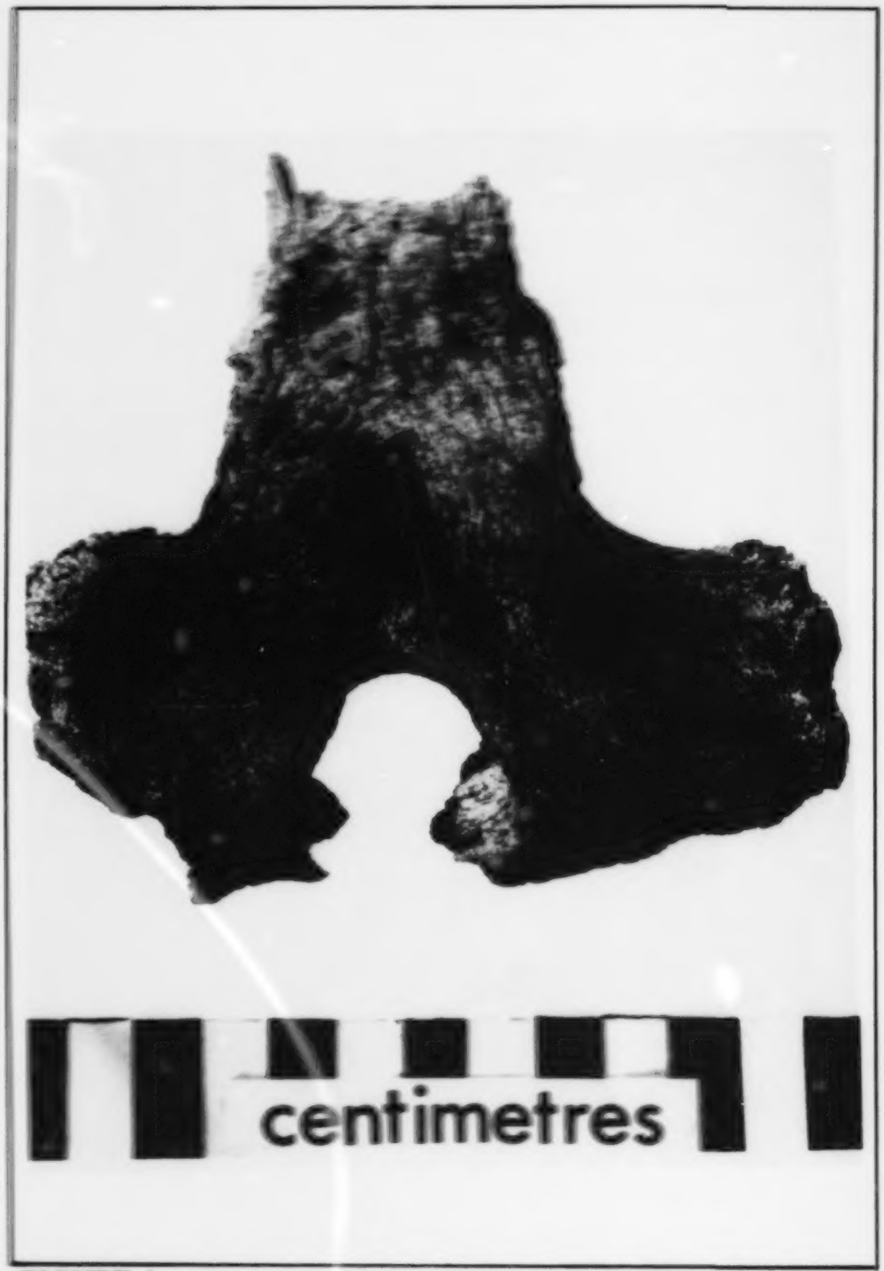


FIGURE 2: Bottom view of the basioccipital region of a tundra muskox (Ovibos moschatus; BM(NH) M3719) skull. Collected by members of the Nares Expedition from raised beach deposits near Alert, Ellesmere Island.

Summer and Richard's islands, as well as "Immerk" in Mackenzie Bay). J.S. Vincent (personal communication, 1985) considers that fragments of mammoth (*Mammuthus* sp.) and tundra muskox (cf. *Ovibos moschatus*) from Garry Island are probably of early Wisconsin age.

Bones of a small sea bird, the Dovekie (*Alle alle*), have been found in middle Wisconsin (about 40,000 years ago) deposits at Cape Storm on southern Ellesmere Island (Blake 1980). This was the first recorded evidence of a Pleistocene bird from the Canadian High Arctic; and the presence of an immature individual may mark the place as a former breeding colony. Until a recent report of two nesting sites at Home Bay, Baffin Island, no Dovekie breeding colonies were known in the Canadian Arctic (Finley and Evans 1984). Marine shells from the fossil-bearing deposit indicate a shallow marine environment with subfrigid to cold-temperate conditions in this ice-free enclave.

Possibly tundra muskoxen (*Ovibos moschatus*) survived the Wisconsin glaciation in a western Banks Island refugium, for remains from Bernard and Masik river areas have been radiocarbon dated at >34,000 yr B.P. and about 11,000 yr B.P. respectively (Maher 1968; Harington 1978).

Apparently several species of land mammals lived in the archipelago during the late Wisconsin, in addition to the muskox mentioned above. They include: mammoth (*Mammuthus* sp.; Figure 3) from Melville Island (about 22,000 yr B.P.), and possibly another one of this age or earlier from northern Banks Island (personal communication, L.V. Hills, 1977); small horse (*Equus lambei*) from Herschel Island (about 16,000 yr B.P.); and saiga antelope (*Saiga tatarica*) from Baillie Islands (about 15,000 yr B.P.). The Melville Island mammoth tusk deserves further comment. It is the most northerly record of a mammoth in North America. It is difficult to explain the presence of mammoths in this rather isolated region near the peak of the last glaciation, but it should be noted that much of the island seems to have been deglaciated before 18,000 years ago (Dyke and Prest 1986). Of great interest paleoclimatically is the saiga skull fragment from Baillie Islands (Figure 4). Presumably it, with mammoth, small horse and some bison fossils from that locality, is indicative of steppe-like grasslands along the arctic coast or northwestern North America during the late Wisconsin (Harington 1981). Other specimens of late Pleistocene (late Wisconsin?) age from Herschel Island include: woolly mammoth (*Mammuthus primigenius*); small horse (*Equus lambei*); large-horned bison (*Bison priscus*); helmeted muskox (cf. *Symbos cavifrons*); and tundra muskox (*Ovibos moschatus*) (Harington 1989).

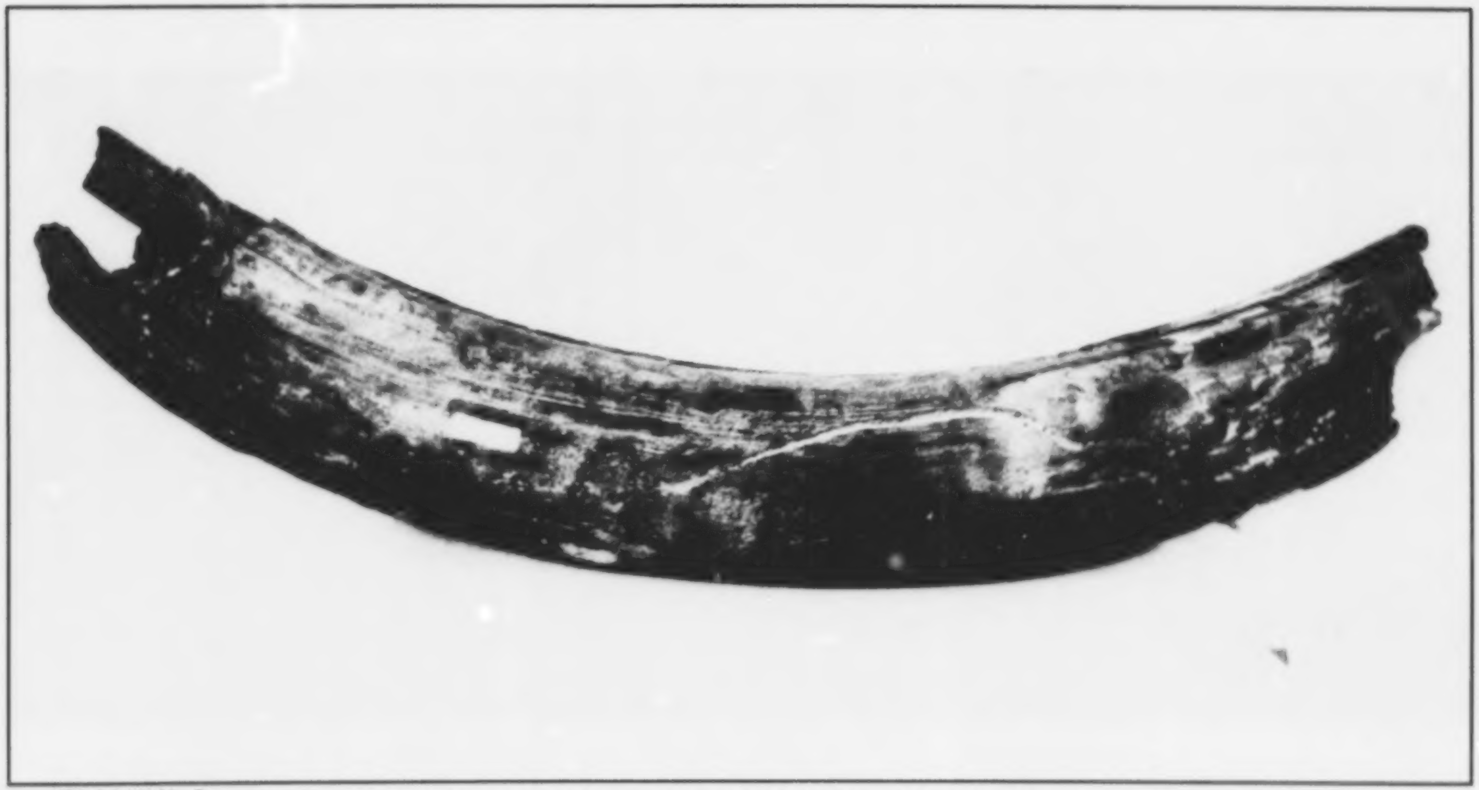


FIGURE 3: Side view of a partial mammoth (Mammuthus sp.; NMC 11833) tusk from Cape James Ross, Melville Island. Collected by members of Stefansson's party during the Canadian Arctic Expedition.

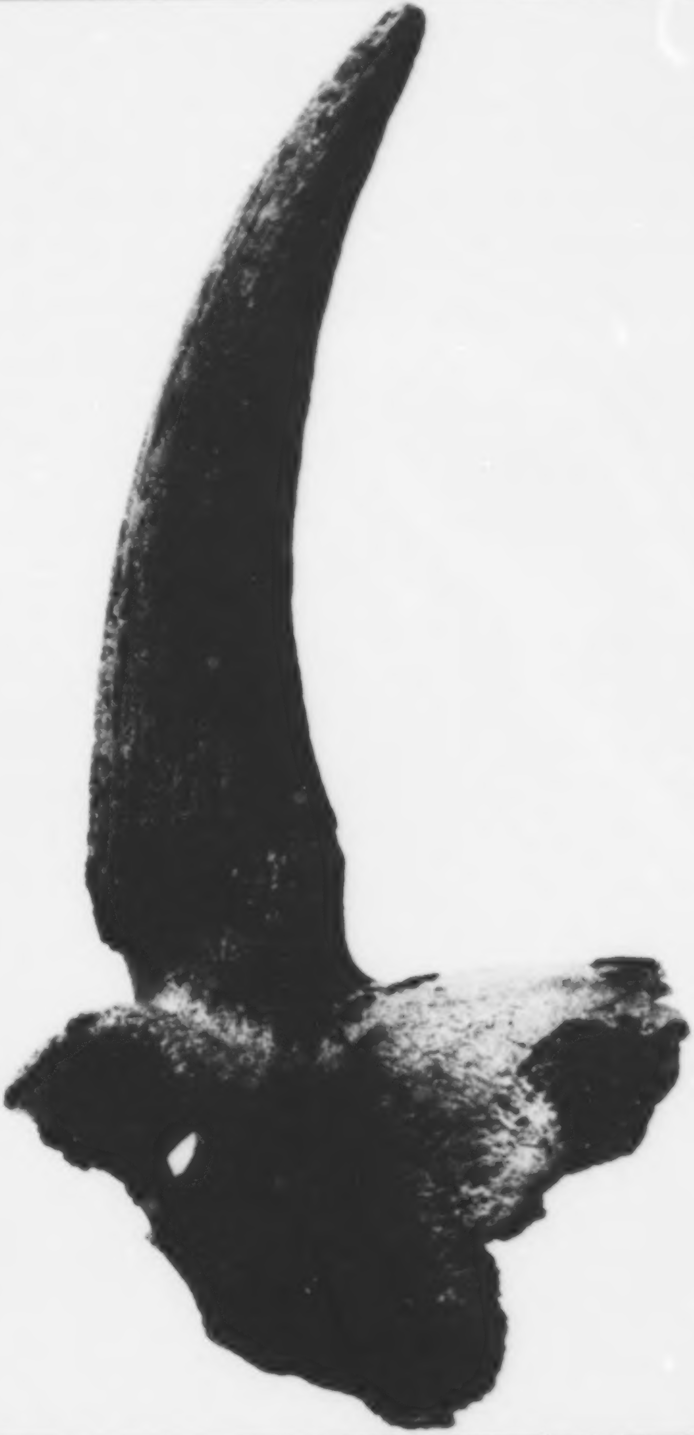


FIGURE 4: Fragment of the left side of a saiga antelope (Saiga tatarica; NMC 12090) cranium with horncore from Baillie Islands.

HOLOCENE VERTEBRATES

Following the megafaunal extinctions near the end of the last glaciation, we are left with the modern vertebrate fauna of the Canadian Arctic Islands. It is worth considering this Holocene evidence carefully because it not only yields information on the changing ranges of various species during the present interglacial, but it has important paleoclimatic implications. In the early Holocene (about 10,000 to 5,000 years ago), several species of vertebrates occupied northern Ellesmere Island. Fielden (Fielden and De Rance 1878), a member of Nares' Royal Navy expedition, collected ringed seal (*Phoca hispida*), collared lemming (*Dicrostonyx torquatus*), caribou (*Rangifer tarandus*), and tundra muskox (*Ovibos moschatus*) specimens from raised-beach deposits near Alert. Perhaps they are of similar age to finds of Oldsquaw duck (*Clangula hyemalis*; Figure 5), narwhal (*Monodon monoceras*), and Peary caribou (*Rangifer tarandus* cf. *pearyi*) from west of Alert that range in age from about 8,500 to 7,000 years ago. Presumably these species were able to migrate into tundra-like areas and coastal waters on the northern margins of the Ellesmere Ice Cap as early as 8,500 years ago, if indeed some did not survive the peak of the Wisconsin glaciation in refuges there. Probably Oldsquaw were migrating to and breeding in northern Ellesmere Island some 7,000 years ago. The species, adapted to tundra lakes and ponds near seacoasts in summer, still breeds in the area (Godfrey 1986). Presumably the narwhal mentioned reached the area during a relatively warm period about 7,000 years ago – well before the ice shelf began to grow about mid-Holocene time. The tusk is 400 to 700 km beyond the range of recently recorded narwhals (Evans 1989).

Farther south, in central Bathurst Island, remains of walrus and tundra muskoxen dating about 7,000 yr B.P. indicate that the ice sheet covering that region during the last glaciation had withdrawn sufficiently to allow immigration of muskoxen - perhaps from refuges in western Banks Island (Harington 1980), as well as a rapid melting of sea ice allowing marine mammals to enter the area. Bowhead whales (*Balaena mysticetus*) had also penetrated that region according to a radiocarbon date on bone from nearby Cornwallis Island (Blake 1970), as well as many other parts of the Arctic Islands during the early Holocene (e.g. Ellesmere (Cape Storm), Devon, Griffith, Somerset and Victoria islands). During the last decade, A.S. Dyke's (1979; personal communication, 1989) field collecting and radiocarbon dating of scores of bowhead remains from raised beaches in the vicinity of

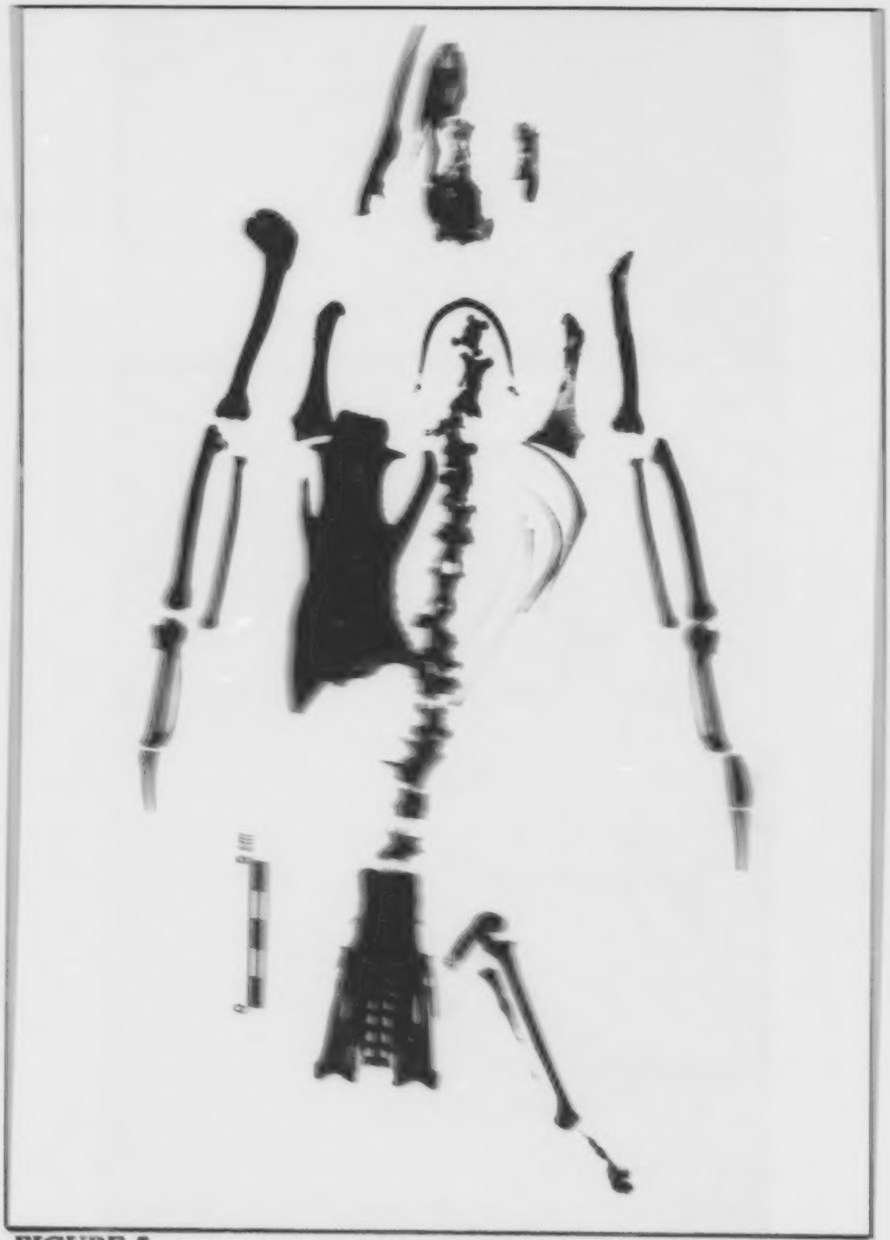


FIGURE 5: Partial skeleton of an individual Oldsquaw duck (Clangula hyemalis); NMC 43777) from Clements Markham Inlet, Ellesmere Island.

Prince Prince of Wales, Somerset and Baffin islands suggest that these whales were relatively common during the summers from about 10,000 to 8,500 years ago, and were somewhat less abundant from 5,000 to 3,000 years ago. Presumably bowheads were largely excluded by relatively solid summer sea-ice conditions in the intervening period, and after 3,000 years ago. It is worth noting that this evidence for more open marine conditions seems to coincide with glaciological records of increasing postglacial warmth 10,000 to 8,300 years ago, following which temperatures reached a plateau until the period of maximum postglacial warmth between 5,000 and 4,500 years ago (Fisher and Koerner 1980). Further, Evans (1989) has summarized glaciological and geomorphological data indicating deteriorating climate in the Canadian High Arctic after about 3,000 years ago.

Because they are rare, or of unusual interest, I have mentioned radiocarbon dates on a few late Holocene (about 5,000 years ago to the present) mammals indicating the presence of polar bears near Prince of Wales Island about 2,000 years ago, lemmings on Bathurst Island at least 4,000 years ago, and bison on Baillie Islands nearly 2,000 years ago.

FUTURE

Existing evidence suggests that discoveries of rich Pleistocene land vertebrate faunas in the Canadian Arctic Islands will be rare. To date, vertebrate paleontologists have relied heavily on Quaternary geologists (who habitually look very closely at surficial deposits and have a good chance of finding fossil bones) for specimens from this vast region - one that is relatively expensive to penetrate and in which paleontological field seasons are necessarily short.

Table 1 shows that field workers in various disciplines have picked up casually many interesting Pleistocene vertebrate specimens from seven different sites on Herschel Island, so a paleontological reconnaissance there has high priority. Another interesting situation is developing in the vicinity of Baillie Islands where saigas survived in probable steppe-like surroundings until near the close of the last glaciation, and where an unusual enclave of bison (probably wood bison, according to the latest evidence) seems to have survived in the late Holocene. It will be interesting to see if paleobotanical clues will be found that can explain the apparent existence of both steppe-like grassland and wood fern habitat in the area during the late Wisconsin and the late Holocene respectively.

As noted previously, it seems advisable for vertebrate paleontologists to look more closely at the possibility of recovering Pleistocene land vertebrate fossils on Banks Island where rather thick sequences of glacial and interglacial deposits occur, some of which are organic (Harington 1985) (Figure 6). Can we find datable land mammal evidence showing that the area was a Wisconsin refuge for caribou, muskoxen and other species (e.g. Maher 1968)? Can similar evidence be found supporting the existence of refuges elsewhere in the Arctic Islands for migratory birds and land mammals during the last glaciation? We must keep looking.

FIGURE 6: Paleontologist collecting at Morgan Bluffs near Jesse Bay, Banks Island in 1982. Jerry Fitzgerald excavates fossils from a peaty layer.

Remains of Holocene marine mammals scattered on raised beaches throughout the archipelago are already being exploited for their geological and archaeological evidence by workers such as A.S. Dyke and J. Savelle, who are focusing presently on the southern islands of the archipelago. Beyond those values are potentially important paleoclimatic implications stemming from the relationship between marine mammals and their environmental adaptations (Harington 1988). Was there a delay between early Holocene open-water conditions in the southern islands compared to the northern ones? To find out, the investigation must be extended northward.

ACKNOWLEDGEMENTS

I thank the following people for their assistance in building a substantial national collection of Quaternary vertebrate remains from the Arctic Islands: J. Bednarski. W. Blake, Jr., M. Bouchard, D.Campbell, R. Choquette, P.F. Cooper, Jr., S. Dallimore, A.S. Dyke, J. England, D.J.A. Evans, J.G. Fyles, D.A. Gill, D.R. Gray, L.V. Hills, M. Kuc, D.S. Lemmen, S.D. MacDonald, A. Martell, C.G. Matthews, R. Popko, J. Raddi, T. Stewart, J.S. Tener, J.S. Vincent and S. Wolfe. I am also most grateful to George Hobson (Polar Continental Shelf Project) for supporting my 1982 field work at Jesse Bay, Banks Island, and to G.R. Fitzgerald for his assistance at Jesse Bay. The Canadian Wildlife Service kindly allowed me to accompany their biologists on a flight from Old Crow to Herschel Island in 1983. A.J. Sutcliffe (British Museum (Natural History)) provided Figure 2.

REFERENCES

Blake, W., Jr. 1970. Studies of glacial history in Arctic Canada. I. Pumice, radiocarbon dates, and differential postglacial uplift in the eastern Queen Elizabeth Islands. Canadian Journal of Earth Sciences 7(2):634-664.

______. 1974. Studies of glacial history in Arctic Canada. II. Interglacial peat deposits on Bathurst Island. Canadian Journal of Earth Sciences 11(8):1025-1042.

______. 1980. Mid-Wisconsin interstadial deposits beneath Holocene beaches, Cape Storm, Ellesmere Island, Arctic Canada. American Quaternary Association, 6th Biennial Meeting (Orono, Maine, August 18-20, 1980), Abstracts. pp. 26-27.

Dyck, W., J.A. Lowdon, J.G. Fyles, and W. Blake, Jr. 1966. Geological Survey of Canada Radiocarbon Dates V. Geological Survey of Canada, Paper 66-48:1-32.

Dyke, A.S. 1979. Radiocarbon-dated Holocene emergence of Somerset Island, central Canadian Arctic. Geological Survey of Canada, Paper 79-1B:307-318.

______. 1983. Quaternary geology of Somerset Island, District of Franklin. Geological Survey of Canada, Memoir 404:1-32.

Dyke, A.S. and V.K. Prest. 1986. Late Wisconsinan and Holocene retreat of the Laurentide Ice Sheet. Geological Survey of Canada Map 1702A.

Evans, D.J.A. 1989. An early Holocene narwhal tusk from the Canadian High Arctic. Boreas 18:43-50.

Fielden, H.W. and C.E. De Rance. 1878. Geology of the coasts of the arctic lands visited by the British Expedition under Captain Sir George Nares, R.N., K.C.B., F.R.S. Quarterly Journal of the Geological Society of London 34:556-557.

Finley, K.J. and C.R. Evans. 1984. First Canadian breeding record of the Dovekie (*Alle alle*). Arctic 37(3):288-289.

Fisher, D.A. and R.M. Koerner. 1980. Some aspects of climatic change in the High Arctic during the Holocene as deduced from ice cores. In: Quaternary Paleoclimate. Edited by: W.C. Mahaney. Geo-Books, Norwich. pp. 249-271.

Godfrey, W.E. 1966. The birds of Canada. Queen's Printer, Ottawa. 428 pp.

Harington, C.R. 1975. A postglacial walrus (*Odobenus rosmarus*) from Bathurst Island, N.W.T. Canadian Field-Naturalist 89(3):249-261.

______. 1978. Quaternary vertebrate faunas of Canada and Alaska and their suggested chronological sequence. Syllogeus 15:1-105.

______. 1980. Radiocarbon dates on some Quaternary mammals and artifacts from northern North America. Arctic 33(4):815-832.

______.1981. Pleistocene saiga antelopes in North America and their paleoenvironmental implications. In: Quaternary Paleoclimate. Edited by: W.C. Mahaney. Geo-Books, Norwich. pp. 193-225.

______. 1985. Comments on Canadian Pleistocene mammals. Acta Zoologica Fennica 170:193-197.

______. 1988. The impact of changing climate on some vertebrates in the Canadian Arctic. In: Preparing for Climatic Change. Proceedings of the First North American Conference for Climatic Change: A Cooperative Approach (Washington, D.C., October 27-29, 1987), Government Institutes, Inc. pp. 194-209.

______. 1989. Pleistocene vertebrate localities in the Yukon. In: Late Cenozoic History of the Interior Basins of Alaska and the Yukon. Edited by: L.D. Carter, T.D. Hamilton and J.P. Galloway. U.S. Geological Survey Circular 1026:93-98.

______. (in press). Vertebrates of the last interglacial in Canada: a review, with new data. Géographie physique et Quaternaire.

Kindle, E.M. 1924. Note on a mammoth tusk from the Arctic Archipelago. American Journal of Science 8(44):183-185.

Lowdon, J.A. and W. Blake, Jr. 1970. Geological Survey of Canada Radiocarbon Dates IX. Geological Survey of Canada, Paper 70-2B:1-86.

Lowdon, J.A. and W. Blake, Jr.. 1980. Geological Survey of Canada Radiocarbon Dates XX. Geological Survey of Canada, Paper 80-7:1-28.

Maher, W.J. 1968. Muskox bone of possible Wisconsin age from Banks Island, Northwest Territories. Arctic 21(4):260-266.

Miller, R.F. 1985. Report on the fossils from Jesse Bay, Banks Island. Prepared for C.R. Harington, National Museum of Natural Sciences. 23 ms. pp.

Stewart, T.G. and J. England. 1986. An early Holocene caribou antler from northern Ellesmere Island, Canadian Arctic Archipelago. Boreas 15:25-31.

Fox
Trace Lake
July 30 · 87

Illustrated by Brenda Carter

TABLE 1: SOME QUATERNARY VERTEBRATE REMAINS FROM THE CANADIAN ARCTIC ISLANDS[1].

TAXA AND SPECIMENS	LOCALITY	REMARKS
Yukon		
Small seal (*Phoca* sp.). Base of left scapula (NMC 25149)	Herschel Island, Pauline Cove (Herschel Loc. 1). Figure 1.1.	Collected in 1973 with marine mollusc shells by C.R. Harington. Possibly of last (Sangamon) interglacial age (Harington, in press).
Large whale, like a bowhead (Cetacea cf. *Balaena mysticetus*). Skull fragment (NMC 17611)	Herschel Island, south-western part (Herschel Loc. 2). Figure 1.1.	Collected in 1970 by M. Bouchard. Possibly of last (Sangamon) interglacial age (Harington, in press).
Mammoth (*Mammuthus* sp.). Tusk lacking tip (NMC 17612)	Herschel Island, south-western part (Herschel Loc. 2). Figure 1.1.	Collected in 1970 by M. Bouchard. From a relatively young individual, according to the tusk's smallness.
Woolly mammoth (*Mammuthus primigenius*) Upper molar (PMA P65.17.1).	Herschel Island Figure 1.1.	Collected in 1965 by C.G. Matthews. Late Pleistocene.
Small horse (*Equus lambei*). Partial cranium (NMC 43815)	Herschel Island, north-eastern coast (Herschel Loc. 7). Figure 1.1.	Collected by S. Dallimore and S. Wolfe in 1986. In silty sand near top of section (40 m asl). Radiocarbon date: 16,200 ± 150 yr B.P. (RIDDL:SFU-765). (Harington 1989).
Small horse (*Equus lambei*). Second phalanx (NMC 10103)	Herschel Island, Pauline Cove (Herschel Loc. 1). Figure 1.1.	Collected in 1974 by D. Campbell from beach. Probably late Pleistocene.
Small horse (*Equus lambei*). Third phalanx (hoof) (NMC 34408)	Herschel Island, Pauline Cove sandspit (Herschel Loc. 1.). Figure 1.1.	Collected by P.F. Cooper, Jr. in 1973 on surface. Probably late Pleistocene.
Large-horned bison (*Bison priscus*). Right hornsheath (NMC 17708)	Herschel Island, Pauline Cove (Herschel Loc. 1). Figure 1.1.	Collected in 1969 by D.A. Gill from beach. Probably late Pleistocene.
Large-horned bison (*Bison priscus*). Partial left horn-sheath (NMC 17709)	Herschel Island, Pauline Cove (Herschel Loc. 1). Figure 1.1.	Collected in 1969 by D.A. Gill from beach. Probably late Pleistocene.

- -

TAXA AND SPECIMENS	LOCALITY	REMARKS
Bison (*Bison* cf. *priscus*). Left ulna fragment (NMC 43816)	Herschel Island, Pauline Cove (Herschel Loc. 1). Figure 1.1.	Collected in 1986 by R. Collier, S.Dallimore and S. Wolfe from beach.
Bison (*Bison* cf. *priscus*). Distal part of right horncore (NMC 17913)	Herschel Island, Pauline Cove (Herschel Loc. 1.) Figure 1.1.	Collected in 1971 by John Raddi from beach. Probably late Pleistocene.
Helmeted muskox (cf. *Symbos cavifrons*). Right tibia (NMC 17613)	Herschel Island, southwestern part (Herschel Loc. 2). Figure 1.1.	Collected in 1970 by M. Bouchard. Probably late Pleistocene.
Tundra muskox (*Ovibos moschatus*). Posterior of cranium with horncores of a very large adult male (NMC 17678)	Herschel Island, central region (Herschel Loc. 3). Figure 1.1.	Collected in 1969 by D.A. Gill from valley bottom west of the island's main lake. Probably late Pleistocene.
Northwest Territories		
Dovekie (*Alle alle*). right ulna (NMC 34551) and sternum of an immature individual (NMC 43813)	Ellesmere Island, 6.5 km north of Cape Storm. Figure 1.21.	Collected in 1975 by W. Blake, Jr. Probably mid-Wisconsin as indicated by six radiocarbon dates on algae and mollusc shells of about 40,000 yrs B.P. (Blake 1980). Immature specimen may indicate a former breeding colony.
Oldsquaw (*Clangula hyemalis*). Most of a skeleton (NMC 43777; Figure 5).	Ellesmere Island, Clements Markham Inlet (82°36'N, 68°31'W). Figure 1.24.	Collected about 1983 by T. Stewart from raised beach deposits about 7,000 yr B.P. Soft tissue still adheres to sternum.
Ptarmigan-like bird (cf. *Lagopus* sp.). Right carpometacarpus fragment (NMC 34816)	Banks Island, Morgan Bluffs near Jesse Bay. Figure 1.9.	Collected in 1977 by J.S. Vincent. Probably from an interglacial about 700,000 yr B.P.
Bird (Aves). Partial feather ("DFTR 86-03")	Ellesmere Island, Thores River. Figure 1.23.	Collected in 1985 by D.S. Lemmen. According to him the feather is probably between 7,700 yr B.P. and about 31,000 yr B.P. (date on associated, possibly reworked mosses).

TAXA AND SPECIMENS	LOCALITY	REMARKS
Collared lemming *(Dicrostonyx torquatus)*. Right mandible with teeth (NMC 34814) and right mandible (NMC 34815)	Banks Island, Morgan Bluffs near Jesse Bay. Figure 1.9.	Collected in 1977 by J.S. Vincent. Probably from an interglacial about 700,000 yr B.P.
Collared lemming *(Dicrostonyx torquatus)*. Unspecified bone	Ellesmere Island, near Alert. Figure 1.25.	From raised beach deposits. Probably early Holocene (Fielden and DeRance 1878; Harington 1978).
Lemming (*Lemmus* or *Dicrostonyx*). Unspecified bone	Bathurst Island, near Muskox River (75°45'N, 98°32'W). Figure 1.15.	From sediment overlying till. Radiocarbon date: 4,070 ± 140 yr B.P. (GSC-401) (Dyck *et al.* 1966, p. 27).
Polar bear (*Ursus maritimus*). Canine teeth with scattered bones of a skeleton (not collected)	Prince of Wales Island, 19 km north-northeast of Cape Richard Collinson and 2.4 km inland. Figure 1.14.	Collected by A.S. Dyke from raised beach (64 m asl). Radiocarbon date of 1,975 ± 120 yr B.P. (Beta-18929) indicates specimen is not contemporaneous with beach formation.
Ringed seal (*Phoca hispida*). Unspecified bone.	Ellesmere Island, Alert area. Figure 1.25.	From raised beach deposits. Probably early Holocene (Fielden and De Rance 1878; Harington 1978).
Small seal (*Phoca* sp.,). A partial skeleton of an adult (NMC 43817).	Ellesmere Island, Clements Markham Inlet (82°36.5'N, 68°31'W). Figure 1.24.	Collected in 1979 by J. Bednarski from glaciomarine silts (6.5 m asl). Probably Holocene (8,000-2,000 yr B.P.).
Walrus (*Odobenus rosmarus*). Tusk	Cornwallis Island (75°01.2N, 93°34'W). Figure 1.17.	Collected from a raised beach (120-150 m asl). Radiocarbon date: 3,510 ± 50 (GSC-2951).
Walrus (*Odobenus rosmarus*). Anterior cranial fragment with right tusk (NMC 13747)	Bathurst Island, about 16 km west of Goodsir Inlet. Figure 1.15.	Collected in 1973 by D.A. Gill from sediments about 53 m asl. Radiocarbon date: 7,320 ± 120 yr B.P. (I-7796). (Harington 1975).

- -

TAXA AND SPECIMENS	LOCALITY	REMARKS
Narwhal (*Monodon monoceras*). Tusk (NMC 44747)	Ellesmere Island, behind the ice shelf 24 km east-northeast of Cape Woods (82°16'N, 85°20'W). Figure 1.22.	Collected at 34 m asl in 1986 by D.J.A. Evans. A radiocarbon date of 6,830 ± 50 yr B.P. (To -.476) was obtained (Evans 1989).
Bowhead whale (*Balaena mysticetus*). Right tympanic (earbone) (NMC 43536) from a skull	Victoria Island, 6.5 km southwest of Cape Wollaston (71°04.5'N, 118°11'W). Figure 1.8.	Collected in 1982 by J.S. Vincent from a raised beach (21 m asl). Radiocarbon date: 9,285 ± 140 yr B.P. (S-2729).
Large whale, probably a bowhead (Cetacea cf. *Balaena mysticetus*). Skull	Devon Island, 4 km north of the head of Truelove Inlet. Figure 1.20.	In yellow silty sand (38 m asl). Radiocarbon date: 8,270 ± 150 yr B.P. (GSC-991) (Lowdon and Blake 1970, p. 82).
Bowhead whale (*Balaena mysticetus*). Vertebra	Somerset Island, 11 km inland from the mouth of Cunningham River. Figure 1.18.	From the surface of marine silt. Radiocarbon date: 8,990 ± 140 yr B.P. (GSC-450) (Dyck *et al.* 1966, p. 27).
Large whale, like a bowhead (Cetacea cf. *Balaena mysticetus*). Rib	Ellesmere Island, 7.5 km north of Cape Storm. Figure 1.21.	Embedded in beach gravel (23 m asl) and exposed in a gully. Radiocarbon dates: 5,600 ± 60 yr B.P. (GSC-979), 5,420 ± 70 yr B.P. (GSC-979-2), 5,050 ± 180 yr B.P. (GSC-979-3) (Lowdon and Blake 1980, p. 18).
Large whale, probably a bowhead (Cetacea cf. *Balaena mysticetus*). Vertebra	Cornwallis Island, near Resolute (74°42'N, 94°59'W). Figure 1.17.	Sample from sand and gravel of a shingle beach 50 ± 10 m asl yielded a radiocarbon date of 7,380 ± 140 yr B.P. (GSC-1193) (Blake 1970).
Probably a large whale (Cetacea). Skull more than 2 m long	Ellesmere Island, 7.5 km north of Cape Storm (76°24.5'N, 98°30'W). Figure 1.21.	In frozen beach gravel (38 m asl). Radiocarbon date: 7,260 ± 80 yr B.P. (GSC-1498), 6,560 ± 170 yr B.P. (GSC-1498-2), 7,240 ± 80 yr B.P. (GSC 1498-3) (Lowdon and Blake, 1980, p. 18).

- -

TAXA AND SPECIMENS	LOCALITY	REMARKS
Large whale (Cetacea). Rib	Victoria Island, 29 km north of Ferguson Lake. Figure 1.13.	From sand at 113 m asl. Radiocarbon date: 8,640 ± 140 yr B.P. (GSC-266).
Large whale (Cetacea). Unspecified bone	Griffith Island, southwestern part (74°33'N, 95°30'W). Figure 1.16.	From a raised beach. Radiocarbon date: "5,000 ± 60 B.C., 6,040 ± 60" (P-2141) (see Radiocarbon 19(2):224).
Probably whale (Cetacea). Unspecified bone	Somerset Island. Northwest coast (73°55'40"N, 90°37'30"W). Figure 1.19.	Associated with marine mollusc shells at 76 m asl, and radiocarbon dated at 9,210 ± 120 yr B.P. (S-1405) (Dyke 1983, p. 27).
Mammoth (*Mammuthus* sp.). Tusk fragment (NMC 43785)	Garry Island, Southwestern part (69°28.5'N, 135° 37.5'W). Figure 1.3.	Collected in 1985 by J.S. Vincent. Probably from early Wisconsin outwash deposits.
Mammoth (*Mammuthus* sp.). Tusk fragment (NMC 11833 Figure 3)	Melville Island. Cape James Ross. Figure 1.12.	Collected by members of the Canadian Arctic Expedition (1913-1918). Radiocarbon date: 21,900 ± 320 yr B.P. (GSC-1760) (Kindle 1924; Blake 1974; Harington 1978).
Mammoth (*Mammuthus* sp.). Tibia shaft (NMC 38655)	Banks Island, Ballast Brook area (74°18'N, 123°05'W). Figure 1.11.	Collected in 1976 by L.V. Hills near the top of a 36.6 m bluff in dark sand. Presumably of Banks Glaciation age or later.
Small horse (*Equus lambei*). Left humerus (NMC 10101)	Mackenzie Bay, near "Immerk", man-made drilling platform. Figure 1.2.	Specimen donated by R. Choquette in 1973. It was dredged from beneath about 3 m of water and 13 m of sea-bottom sediment. Probably late Pleistocene.
Small horse (*Equus lambei*). Right radius (NMC 13741)	Richards Island, Ya Ya Lake. Figure 1.4.	Collected in 1972 by A.M. Martell. Probably late Pleistocene.

- -

TAXA AND SPECIMENS	LOCALITY	REMARKS
Small horse (*Equus lambei*). Right metacarpal	Summer Island, north side (69°36.4'N, 134°53'W). Figure 1.4.	Collected in 1986 by J.S. Vincent from beach. Sediments exposed nearby are Kidluit (last, or an earlier interglacial) or Kittigazuit Formation sediments underlain by till of the Toker Point Stade.
Peary caribou (*Rangifer tarandus* cf. *pearyi*). Left antler of an adult male (shed) (NMC 42302)	Ellesmere Island, north end of Piper Pass. Figure 1.24.	Collected about 1983 by T. Stewart. Radiocarbon date: 8,415 ± 135 yr B.P. (S-2501) (Stewart and England 1986).
Caribou (*Rangifer tarandus*). Right mandible fragment with teeth (NMC 17685)	Banks Island, Masik River area (71°35'N, 123°27'W). Figure 1.7.	Collected in 1969 by M. Kuc from a laminated sand with plant remains. Possibly late Pleistocene or early Holocene.
Caribou (*Rangifer tarandus*). Metapodial fragment (NMC 10500) and antler fragments (NMC 10499)	Baillie Islands. Figure 1.5.	Collected in 1965 by J.G. Fyles. Heavily water eroded.
Bison (*Bison* sp.). Third cervical vertebra	Richards Island, northern part (69°29.8'N, 133°54.3'W). Figure 1.4.	Collected in 1986 by J.S. Vincent from the surface of the Kidluit Formation sediments (last or older interglacial), and could have come from those sediments.
Probably wood bison (*Bison bison athabascae*). Partial right hornsheath (NMC 17505). There may be earlier bison remains too (NMC 10501-10505, 12086-12088, 17503-17504)	Baillie Islands, eastern shore. Figure 1.5.	Collected in 1969 by V. Rampton and J.G. Fyles on the beach. Radiocarbon date: 1,810 ± 90 yr B.P. (I-5407) (Harington 1980). Suggests that an enclave of wood bison may have existed recently near the Beaufort Sea coast.
Saiga antelope (*Saiga tatarica*). Left posterior portion of cranium with left horncore (NMC 12090; Figure 4)	Baillie Islands. Figure 1.5.	Collected in 1969 by J.G. Fyles on the beach. Radiocarbon date: 14,920 ± 160 yr B.P. (Beta-25119 ETH-3898). Indicates that saigas survived in northeastern Canada until near the close of the Wisconsin glaciation.

- -

TAXA AND SPECIMENS	LOCALITY	REMARKS
Tundra muskox (*Ovibos moschatus*). Metapodial (sacrificed for radiocarbon dating)	Banks Island, Bernard River. (73°23'N, 120°54'W). Figure 1.10.	Collected from a gravel bar on the river. Radiocarbon date: >34,000 yr B.P. (S-288) (Maher 1968).
Tundra muskox (*Ovibos moschatus*). Right horncore with part of right side of brain case of a female (NMC 34511)	Bathurst Island, 16 km west of Goodsir Inlet. Figure 1.15.	Collected in 1976 by R. Popko and D.R. Gray. Apparently washed into creek bed from sediments nearby. Radiocarbon date: 6,725 ± 130 yr B.P. (I-10919) (Harington 1980).
Tundra muskox (*Ovibos moschatus*). Right mandible with teeth of an adult (uncatalogued)	Bathurst Island, approximately 16 km west of Goodsir Inlet. Figure 1.15.	Collected in 1973 by J.S. Tener from a peat hummock. Radiocarbon date: 2,950 ± 90 yr B.P. (I-9996) (Harington 1980).
Tundra muskox (*Ovibos moschatus*). Left tibia (NMC 17909)	Bathurst Island, 16 km west of Goodsir Inlet (75°43'N, 98°25'W). Figure 1.15.	Collected in 1975 by D.A. Gill from peat bed exposed in creek. Holocene?
Tundra muskox (*Ovibos moschatus*). Cranium, left humerus and partial right humerus of an adult male (NMC 44364)	Banks Island, Jesse Bay. Figure 1.9.	Collected in 1982 by C.R. Harington and G.R. Fitzgerald from surface sediments north of Morgan Bluffs. Holocene?
Tundra muskox (*Ovibos moschatus*). Left pelvic fragment (NMC 11337)	Banks Island, southwest coast 14 km north of Masik River. Figure 1.7.	Collected in 1963 by J.G. Fyles near the base of a 1.5 m layer of alluvium overlying a sand terrace. Plant debris enclosing the bone was radiocarbon dated at 10,600 ± 170 yr B.P. (GSC-240) (Harington 1978).
Tundra muskox (*Ovibos moschatus*). Basiocipital bone (BM(NH) M 3719; Figure 2)	Ellesmere Island, near Alert. Figure 1.25.	From raised beach deposits. Presumably early Holocene (Fielden and DeRance 1878; Harington 1978).
Tundra muskox (cf. *Ovibos moschatus*). Rib fragment (NMC 43784)	Garry Island, southeastern part (69°28.5'N, 135°37.5'W). Figure 1.3.	Collected in 1985 by J.S. Vincent. Probably from early Wisconsin outwash deposits.

TAXA AND SPECIMENS	LOCALITY	REMARKS
Large mammal (Mammalia). Probably part of a limb bone (like a horse or bison metapodial) (NMC 45295)	Richards Island, Near the northern tip (69°43'N, 134°28'W). Figure 1.4.	Apparently collected in 1987 from a 10-cm diameter nearshore drill hole (via S.R.Dallimore). From about 28 m below sea level in frozen gray organic sand. Possibly from the Kidluit Formation or older Kendall Sediments. Last interglacial or earlier.
Medium-sized mammal (Mammalia). Three fragments of cortical bone from a limb(?) bone (NMC 38656)	Banks Island, Duck Hawk Bluff (71°58'N, 125°40'N). Figure 1.6.	Collected in 1983 by J.S. Vincent and attributed by him to the Morgan Bluffs Interglaciation (about 700,000 years old).

---

[1] This list focuses mainly on land vertebrates older than 5,000 years. Herschel Island is included as one of the Canadian Arctic Islands, as are some of the islands near the mouth of the Mackenzie Delta, as well as Baillie Islands.

Illustrated by Brenda Carter

RATES OF DECAY OF MAMMALIAN REMAINS IN THE PERMAFROST ENVIRONMENT OF THE CANADIAN HIGH ARCTIC

Antony J. Sutcliffe[1]

Abstract: In the permafrost environment mammalian remains, which at lower latitudes would decay rather quickly, are often preserved for a very long time. In the permafrost itself complete carcasses may survive almost indefinitely; for example those of mammoths and bison from Siberia and Alaska, some of which are over 40,000 years old.

Although only a few carcasses of such antiquity have been found in Canada, mammalian skeletal remains with soft tissues less than 1,000 years old are widespread in the floor-debris of Thule houses throughout the High Arctic, and there are instances of complete Thule Inuit bodies about 500 years old from Alaska and Greenland.

Mammalian remains may also survive for a long time on the ground surface, although it is not possible to generalize about how quickly decay will occur, since this varies locally (even within the same specimen) in relation to microclimatic conditions. On a dry scree, soft tissues commonly survive on the lower surface of a bone after they have disappeared from the upper; whereas in a damp situation they decay on the lower surface first. Exposed surfaces of bones tend to weather more quickly than those that are sheltered, with distinct zones of lichen and algal growth respectively.

A series of dated mammalian skeletal remains from the Canadian High Arctic provides an indication of the length of time that, under the most favourable conditions, bones can survive on the ground surface. At the Thule archaeological site of Brooman Point, Bathurst Island, bones and bone artifacts are well preserved after 800 years; and an Independence walrus-ivory harpoon head is almost perfect after more than 3,000 years. Well-preserved whale bones on raised beach ridges at diverse localities carry the record of surface remains back 9,000 years.

Résumé: Les vestiges de mammifères se conservent souvent très longtemps dans un environnement de pergélisol, alors que, sous des latitudes inférieures, elles se détérioreraient assez rapidement. Dans le pergélisol même, des carcasses complètes peuvent demeurer intactes presque indéfiniment; par exemple, parmi celles de mammouths et de bisons de Sibérie et d'Alaska, quelques-unes datent de plus de 40 000 ans.

Bien que seulement quelques carcasses aussi anciennes aient été découvertes au Canada, les restes squelettiques de mammifères, avec des tissus mous, datant de moins de mille ans, sont largement répandus dans les débris du sol des habitations de Thulé dans tout le Haut-Arctique. On a également trouvé des corps complets d'Inuit de Thulé datant d'environ 500 ans, qui viennent de l'Alaska et du Groënland.

Les restes de mammifères peuvent aussi se conserver longtemps à la surface du sol, bien qu'il soit impossible de donner des règles générales sur la vitesse de dégradation, car elle varie localement (même dans un seul spécimen) selon les conditions microclimatiques. Dans des conditions sèches, les tissus mous subsistent ordinairement sur la surface inférieure de l'os après être disparus de la surface supérieure, tandis que, dans des conditions humides, ils se désagrègent d'abord sur la surface inférieure. Les surfaces exposées des os ont tendance à plus rapidement que celles qui sont couvertes, accompagnées de prolifération de lichens et d'algues.

Une série de squelettes datés de mammifères, provenant du Haut-Arctique canadien, apporte des indications sur le temps de conservation les os peuvent s'altérer à la surface du sol, dans les meilleures conditions. Sur le site archéologique de Thulé à la pointe Brooman, sur l'île Bathurst, il y a des os et des artéfacts en os qui sont encore bien conservés après 800 ans; une tête de harpon en ivoire de morse de l'Indépendancien est en presque parfait état après lus de 3 000 ans. Des os de baleines sur des cordons littoraux élevés, à divers endroits, sont bien conservés et détiennent le record de temps pour des restes de surface, avec 9 000 ans.

INTRODUCTION

At middle and low latitudes, mammalian carcasses lying on the ground surface soon decompose because of biological processes and weathering. Even bones seldom survive for more than a few decades, their decomposition products becoming potentially available, via the lithosphere, for biological recycling. Only if buried may they sometimes be indefinitely preserved and, even then, it is unusual for their soft parts to survive. The 2,000 year old

---

[1] Department of Palaeontology, British Museum (Natural History), Cromwell Road, London SW7 5BD, U.K.

Iron Age human burials from Danish peat bogs (Glob 1973) and the Upper Pleistocene woolly rhinoceros carcasses from the salty ozokerite deposits of Starunia, eastern Europe (Nowak *et al.* 1930) preserved by unusual chemical conditions, provide notable exceptions.

In the permafrost environment of high latitudes and high altitudes, a totally different state of affairs exists. Bones may survive on the ground surface for thousands of years; and frozen carcasses and other soft parts of mammals and even birds, of diverse ages from Upper Pleistocene to present, are widespread in the underlying sediments.

Best known discoveries of mammalian soft tissues preserved by freeze-related processes come from the northern hemisphere, where the greatest expanses of permafrost occur. However, there have also been some remarkable finds in the southern hemisphere. These include: the 13,000 year old fragments of ground-sloth skin from the Cave of Ultima Esperanza, Patagonia, which Harris (Sutcliffe 1985) concluded had been freeze-dried; the magnificently preserved 500 year old clothed body of an Inca child from an altitude of 5,400 m on El Plomo Peak, Chile (33°S) (McIntyre 1973); and seal carcasses from the ground surface of the "dry" valleys of Antarctica (Dort 1975).

In the northern hemisphere, permafrost underlies a vast circumpolar area extending through Alaska, northern Canada, Greenland, Spitsbergen, northern Scandinavia and Siberia (where it reaches its greatest known depth of 1,450 m at the Shalagonski Settlement in northwestern Yakutia). The southern limit of continuous permafrost varies from 68°N in Alaska to as far south as 59° in Siberia and 55° in Canada's Hudson Bay region. South of these regions there is a further zone of discontinuous permafrost of varying width (Péwé 1969). Mammalian (including human) remains, with their soft parts preserved by freezing to various degrees, have been found in the continuous permafrost zones of all the above-mentioned land areas; but rarely in the northern part of the discontinuous permafrost zone.

These remains are not all of the same age, but range over a considerable period. The earliest mammal-related frozen material pertinent here are excellently preserved small mammal droppings from the Miocene-Pliocene Beaufort Formation of Meighen Island, N.W.T. (79°N), although these may owe their preservation to the peaty nature of the matrix (which also contains well-preserved plant and insect remains) rather than to freezing. So far no remains, even bones, of the animals concerned have been discovered, but the deposit merits continued surveillance.

Most remarkable of all the permafrost discoveries are the Pleistocene carcasses of Siberia and Alaska (map of principal discoveries in Sutcliffe 1985). Animals represented in Siberia include: many woolly mammoth carcasses (e.g. Pfizenmayer 1939; Garrutt 1964; Shilo 1983; Sokolov 1982; Vereshchagin 1974; Vereshchagin and Mikhelson 1981), woolly rhinoceros (Lazarev 1977), horse (Skarlato 1977), bison, wolverine (Vereshchagin 1977), ground squirrel (Vinogradov 1948), vole and ptarmigan. Mammalian carcasses found in Alaska and western Yukon include: mammoth (Anthony 1949), bison (Péwé 1975), pika (Guthrie 1973), extinct muskox (McDonald 1984), black-footed ferret (Youngman 1987), caribou and ground squirrel (Harington 1984). General reviews of these frozen remains are in Guthrie (1972), Péwé (1975) and Harington (1978).

Radiocarbon dates now available for many of these remains fall into two main groups: one (including the Siberian Shandrin and Khatanga mammoths, 'Dima', and a bison from Fairbanks) ranging from about 45,000-30,000 years; and another including a smaller number of remains about 14,000-10,000 years old. The Siberian Yuribei mammoth, with a radiocarbon date of only about 9,700 years, is of Holocene age. In spite of the antiquity of these frozen remains, their state of preservation is often remarkable, allowing detailed histological studies. In the Shandrin and Yuribei mammoths, even larvae of the stomach bot-fly (*Cobboldia*) were preserved (Grunin 1973; Vereshchagin 1982).

A frozen carcass of a whale, estimated to be between 2,500 and 200 years old, found in 1954 entombed in the ice-cored moraine of Sveabreen, Ekmanfjord, Vestspitzbergen (78°N) was reported by Dineley and Garrett (1959).

No less remarkable than the mostly Pleistocene frozen remains mentioned above are those dating from the last millennium, many of them of special interest because of their archaeological or historical context. These include clothed Inuit bodies believed to be about 500 years old from Utqiagvik, near Point Barrow, Alaska (71°N) (Dekin 1987) and from Quilakitsoq, near Uummannaq, western Greenland (71°N) (Hansen *et al.* 1985); and the bodies of three crew members of Sir John Franklin's expedition in search of the North-West Passage, who were buried on Beechey Island, southwestern Devon Island (75°N) in 1846 and recently temporarily disinterred for study (Beattie and Geiger 1987).

There are also many mammalian skeletal remains from the last few millennia lying on the ground surface in various stages of decay. Some of the later examples have the more resistant soft-parts still preserved. The rest of this paper focuses on a more detailed study of these mainly surface remains in the Canadian High Arctic.

THE CANADIAN HIGH ARCTIC

It has long been recognized by Arctic travellers that some mammalian bones seen lying on the ground - especially those of whales and seals on the raised beaches and bones at Inuit archaeological sites - are of considerable age. The abundance and beauty of the lichens growing on them has also attracted attention. More than a century ago Nares (1878) recorded "... we found at Cape Sabine, Ellesmere Land, the remains of several ancient Eskimo encampments as well as an old sledge made of walrus bones, with cross-bars of narwhal horn, completely lichen-covered and of such antiquity that the bones were friable ...". Greely (1886), described the differential preservation of a bone from northern Ellesmere Island: "... evidently it is part of a native sledge of the cellular bone of a whale ... One side was covered with lichens ... and was so affected by exposure as to be almost unrecognizable as bone. The reverse side, however, showed plainly the marks of the knife".

Although scientists, especially archaeologists, working in the Arctic have long since become familiar with the differing states of preservation of ancient mammalian remains such as these, so far no general review of the rates and processes of decay involved (including whether the ages of bones can be accurately estimated from their appearance) has been attempted. The Canadian Arctic Islands offer an ideal environment for such a study. Not only do they provide a vast area of mostly glacier-free permafrost terrain that for thousands of years has been a rich ground for the accumulation of mammalian bones, but their remoteness has protected them from human interference of the sort that, in a populated area, would long ago have led to their destruction. Diverse methods of dating (radiocarbon and altimetric methods for the remains from the raised beaches, archaeological and historical evidence for the later remains) now provide a chronological framework reaching back nearly 9,000 years to which the various stages of decay can be related.

In a region where shortage of organic nutrients is a major factor inhibiting plant growth, the rate at which the decomposition products of bone can return to the soil is significant to plant-productivity. In some arctic desert areas (e.g. Brooman Point on Bathurst Island), patches of moss provide a certain indicator of underlying fragments of bone, some so small that they would otherwise be difficult to locate. In the less severe environment of nearby Polar Bear Pass, the almost-decayed carcass of a muskox (dead about 12 years, with the skeleton and most of the stomach contents still preserved) is surrounded by a luxuriant growth of grass and poppies on an otherwise poorly-vegetated slope.

STUDY AREA AND ACKNOWLEDGEMENTS

Travelling in the High Arctic is not simple, and the pursuit of scientific work, especially a topic such as this, is largely dependent on the support of others. I gratefully acknowledge the facilities, guardianship, guidance and encouragement received during expeditions based at Resolute in 1975 and 1979, which allowed me to examine in the field a long series of mammalian skeletal remains, most with chronological data, ranging in age from about 7,000 years to specimens that died only a few hours earlier.

Permission to undertake the 1979 part of this study was granted by the Government of the Northwest Territories.

Air transport between sites was provided by the Polar Continental Shelf Project.

Len Hills and John Matthews allowed me to join their 1975 expedition to Meighen Island (79°N) described by Stefansson (1921) as "the most nearly barren land I have seen in the Arctic".

Stu MacDonald and David Gill provided hospitality at the National Museum of Natural Sciences High Arctic Research Station at Polar Bear Pass, Bathurst Island (76°N), during 1975 and 1979; providing access to: a raised-beach whale skull now situated, as the consequence of isostatic uplift, 6 km from the sea; bones chewed by wolves; bones and antlers chewed by arctic foxes; muskox carcasses in various stages of decay; wolf and fox droppings; Snowy Owl pellets containing bones; and much other interesting material.

Bob McGhee allowed the writer to investigate mammalian remains encountered during his 1979 excavation of Dorset and Thule culture dwellings at Brooman Point (McGhee 1978, 1980, 1981, 1984A, 1984B). Of special interest from this site is the 800 year old frozen occupation debris found in the floors of several Thule houses. During the course of the excavation a polar bear conveniently killed a seal on the nearby sea ice, permitting subsequent examination of what was left of that carcass.

Peter Schledermann permitted a similar investigation of mammalian remains, including frozen-floor remains, excavated during 1979 from a Dorset-Thule site at Eskimobyen, Knud Peninsula, Ellesmere Island (79°N), and from a Thule-Viking site on Skraeling Island, Alexandra Fiord (Schledermann 1978, 1981; Arnold and McCullough, this volume). This part of the expedition also enabled me to examine bones around the abandoned Royal Canadian Mounted Police Detachment at Bache Peninsula (occupied 1926-1933) and from the dog enclosure at the Alexandra Fiord Police Detachment (abandoned 1963). A visit to the site where Greely's party tragically spent the winter of 1883-1884 on Pim Island (78°N) (Greely 1886, Powell 1961; Rockwell, this volume) revealed no bones associated with this event. However, the survival of undisturbed canvas and leather fragments on the ground for more than a century, forcefully demonstrates the slowness of decay or organic remains in this arctic environment.

I gratefully acknowledge additional carefully-documented study material, collected by others from the following localities:

From raised beaches: bones or bone fragments of marine mammals from Wes Blake (Cape Herschel, Ellesmere Island (78°N)), Stu MacDonald (Seymour Island (76°N)) and Joseph Svoboda (Devon Island (76°N) and Lake Hazen, Ellesmere Island (82°N)).

From the nineteenth century: muskox, caribou and seal remains (dating from 1855-1890) collected by Cliff Hickey from the ground surface at the *Investigator* site, Mercy Bay, Banks Island (74°N) (Wilkinson and Shank 1975; Parfitt, in preparation), and photographs of remains at this site from W. von Koenigswald; and vertebrae from a muskox shot by Otto Sverdrup in Sverdrup Pass, Ellesmere Island (79°N) during the third week of April, 1899 (Sverdrup 1904), collected by David Gill in 1985, have a uniquely exact date.

Collections of recent caribou and reindeer antlers provide useful comparative data from localities outside the area of the present study: some chewed by these animals and by rodents, collected from Alaska by the Cambridge University Alaska Expedition (1977) and R.E. Nelson in 1978 and 1980; from the mainland Northwest Territories by B. Gordon (1978) and C. Tarnocai (1978); from Spitsbergen by O. Salvigsen (1977) and the Cambridge University Spitsbergen Expedition (1978); as well as my 1971 collection from the Hardangervidda Mountains, Norway in 1971 (Sutcliffe 1973, 1977).

THE EFFECT OF HIGH ARCTIC MICROCLIMATE ON THE RATE OF DECAY OF BONES AND SOFT TISSUES

Let us now look more closely at the way in which mammalian remains disappear from the High Arctic environment. Can their age be assessed from their state of preservation? This is possible to some extent, and there is no High-Arctic archaeologist who has not long been familiar with seeing bones of similar ages and in similar environmental situations in like states of preservation. But here, they found, the similarity ends. Not all remains find their way into comparable situations, and microclimatic differences have a profound influence on their condition. In such studies it is also necessary to consider whether the remains being studied have always rested at the same place and in the same orientation, or whether they have subsequently been moved by human (most likely nineteenth or twentieth century people) or other natural processes. Even under natural conditions, the transfer of remains from one microenvironment to another is not unusual. For example, where a bone is carried down into the ground or brought from a horizontal to vertical position around the margins of an active polygon; where it is disturbed by solifluction; where it becomes buried by peat or by sediment; where it is removed from the zone of salt spray along the sea shore by isostatic uplift of the land; or where a pond dries up or becomes flooded. Nevertheless, a vast reserve of material exists that probably lies in its original situation, unaffected by such changes; and the conclusions drawn from the present study are mainly based on this.

The number of possible microenvironments in which mammalian remains may undergo decomposition in the High Arctic is great. One area that has received detailed microenvironmental study is the Truelove Lowland on Devon Island (76°N) (Bliss 1977). The description of the plant communities and map in that book are of particular relevance. For the purpose of the present study, five factors appear to be important in controlling the rates of decay of mammalian remains: (1) whether the remains are buried (including their relationship to the permafrost) or on the ground surface; (2) the amount of moisture; (3) the pH of the surrounding deposits or substrate; (4) the number of months of annual snow-cover (a bone covered by snow for 10 months of the year is likely to survive much longer than one on a windswept hilltop, which may also experience blasting by wind-carried particles); and (5) the degree of exposure to temperature changes and other atmospheric processes. Commonly not all parts of a bone are exposed to the same environmental conditions. Its underside, in contact with the ground, may remain at freezing-point throughout the summer, whereas its upper surface, baked by the sun, may repeatedly reach quite high temperatures, with associated desiccation.

Plants, by their extraction of nutrients, also contribute to the decay of mammalian remains - their distribution and effect being secondarily related to the environmental zoning just described.

The principal environmental zones investigated during this study (Figure 1) follow.

The Permafrost

Observations on this zone are necessarily limited, since they can be made only where the permafrost has been uncovered, for instance by slumping and in commercial and archaeological excavations. Nevertheless, the condition of mammalian remains preserved in it is often remarkable.

The writer was privileged to examine frozen occupation-debris in the floors of Thule houses being excavated by Schledermann at Eskimobyen and on Skraeling Island, as well as by McGhee at Brooman Point (Figure 2). Household debris included a great variety of mammalian bones (whale, walrus, seal, polar bear, arctic fox, caribou - all with varying amounts of magnificently preserved soft parts, including a seal flipper from Eskimobyen (Figure 3); the entire face and a hind flipper of a walrus, a foot of a caribou, fragments of seal and polar bear skin, bird remains and domestic dog droppings from Brooman Point; baleen, fragments of clothes (including a pair of childs' sealskin mittens tied together with cord from Eskimobyen), and abundant remains of arctic heather and other plants. These remains apparently represent domestic rubbish which had built up sufficiently rapidly on the stone floors of various houses to become permanently frozen - at Brooman Point for more than 800 years; at Eskimobyen probably less than 600 years. All the remains were impregnated with seal oil, which may also have had a preservative effect. This zone of frozen remains was found to end abruptly at its upper limit, at the level to which annual thawing had subsequently penetrated (about 0.4 m at Eskimobyen, and only 0.15 m at Brooman Point).

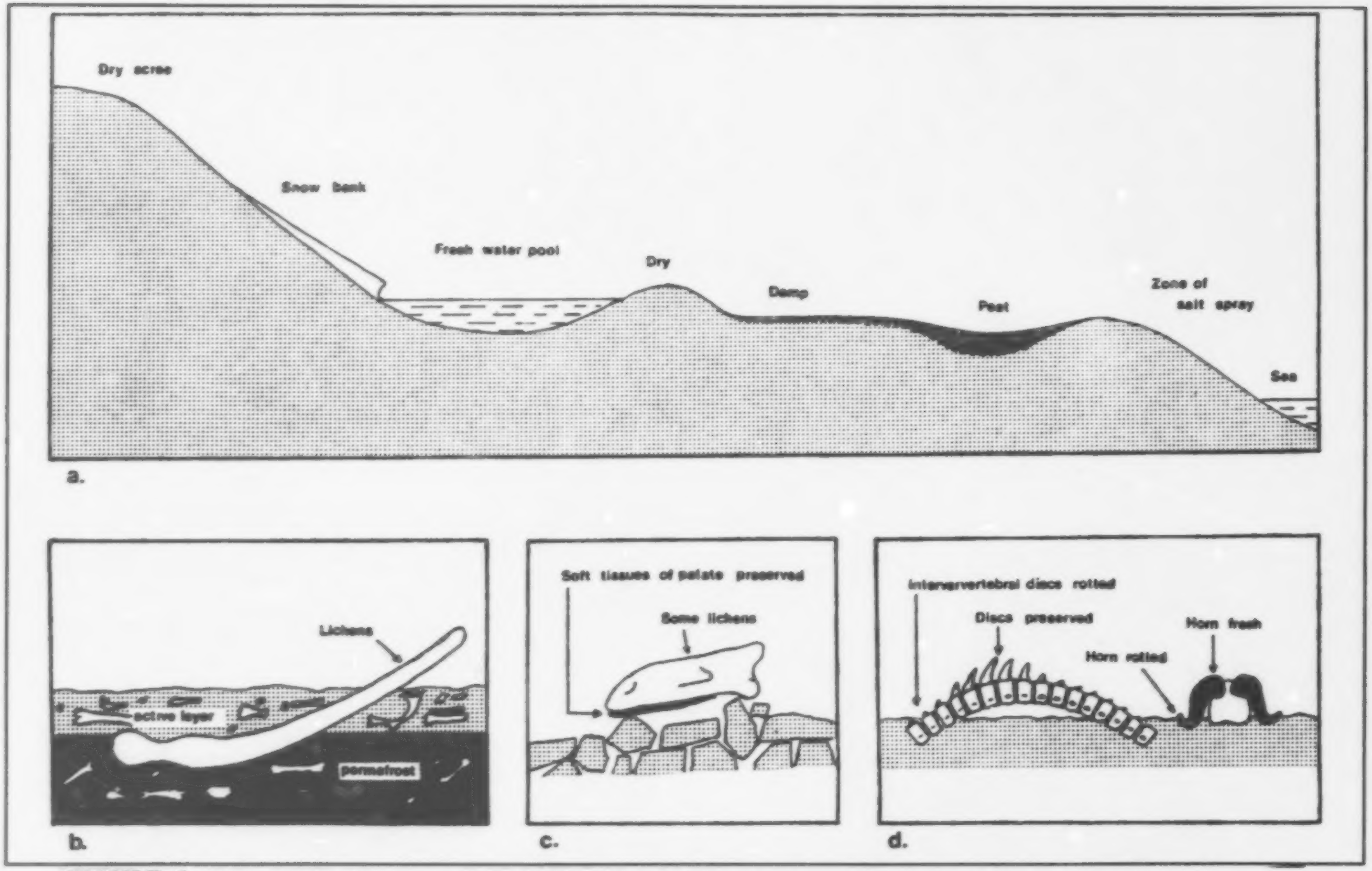

Dry scree
Snow bank
Fresh water pool
Dry
Damp
Peat
Zone of salt spray
Sea
a.
Lichens
active layer
permafrost
b.
Soft tissues of palate preserved
Some lichens
c.
Interververtebral discs rotted
Discs preserved
Horn rotted
Horn fresh
d.

FIGURE 1: (a) Schematic section across an imaginary High Arctic coastal area, showing some of the zones in which bones are likely to show different states of preservation. (b) Schematic section across a deposit where bones occur in three microenvironments (in ascending order): the permafrost, the active layer and above ground. The whale jaw extends through all three zones, and preservation is different in each. Based on floor-debris in Thule houses at Brooman Point, Bathurst Island and Knud Peninsula, Ellesmere Island. (c) Schematic profile of a mammal skull lying on limestone scree; weathered and with lichen growth above, soft tissues of palate still preserved on lower surface. Based on seal skull at Resolute, Cornwallis Island. (d) Schematic profile of a muskox skull and vertebral column, lying on damp ground; horns and intervertebral discs well-preserved above ground, rotted at ground level. Based on remains from Polar Bear Pass, Bathurst Island and from Mercy Bay, Banks Island.

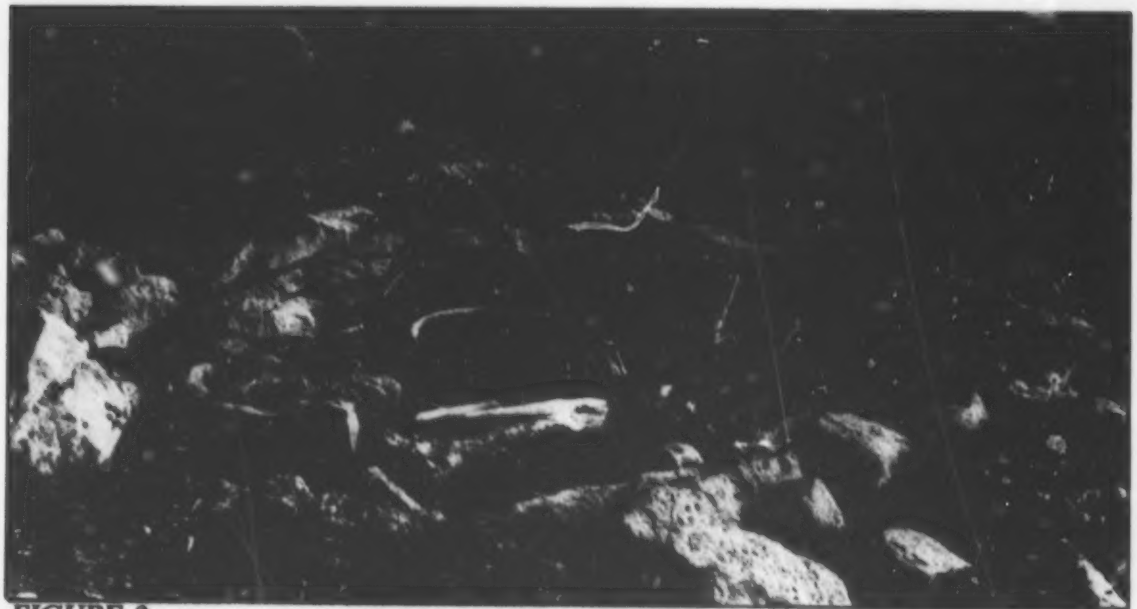


FIGURE 2: Thule house no. 2 at McGhee's site on Brooman Point, Bathurst Island, 1979, before excavation; age about 800 years. Whale jaws and ribs that formerly supported the roof covering, still well-preserved, lie on the ground inside the house wall. Beneath this are frozen floor-deposits containing mammalian bones with soft tissues.

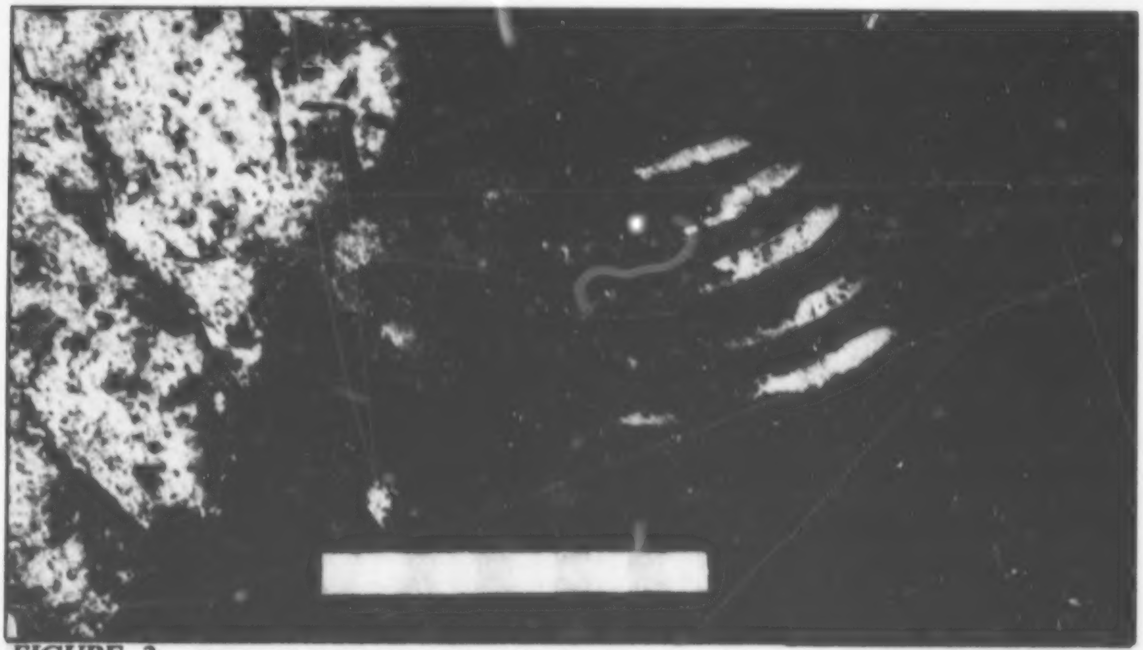


FIGURE 3: Frozen seal flipper in permafrost floor-deposits of Thule house no. 8 at Schledermann's excavation at Eskimobyen, Knud Peninsula, Ellesmere Island, July 1979.

The Active Layer

This deposit was best seen at Brooman Point, where it overlay the permafrost horizon just described. Although containing many well-preserved bones, no associated soft parts survived. Nevertheless, all carried irregular patches of brown staining on their lower surfaces, not present above. Analysis of this substance by G. Jones (Department of Mineralogy, British Museum (Natural History)) gave approximately 35% carbon and 4% nitrogen, suggesting an organic rather than inorganic origin.

The Ground Surface

As previously observed, the state of preservation of mammalian remains lying on the ground varies not only in relation to their age, but also to their microenvironments. Among material dating from the last two centuries it is not uncommon to find that bone decay is proceeding ahead of the decay of associated soft tissues on the more protected surfaces of the same specimens.

Five subenvironments are recognized here.

Dry Scree Slopes and Bare Rock Surfaces

Two stages of decay can be distinguished in this subenvironment - an earlier stage, when some soft parts still survive, and a later one after they have disappeared, leaving only skeletal remains. Most examples studied were on limestone. No data were collected concerning what happens to bones in similar situations on other rock types. A particularly interesting specimen in this category is an imperfect ringed seal skull of uncertain date, found palate downwards on a limestone scree at Resolute on Cornwallis Island (74°N) (Figure 1c). Although the upper surface lacking soft parts, was beginning to flake and already carried a modest lichen growth, the dried soft tissues of the palate were still intact. Remarkably, these also carried a considerable lichen growth.

The archaeological site on the south side of Polar Bear Pass, Bathurst Island, designated OkLg-3 by McGhee, has an associated scatter of fragments of caribou bone resting on a limestone scree and showing preservation (including traces of soft tissues on their lower surfaces, lichens above) reminiscent of the Resolute specimen. McGhee (personal communication) suggests that, unless the site is more than 500 years old, it probably belongs to the nineteenth century. The condition of these remains makes the latter date the most likely.

The limestone screes of Brooman Point also provide a valuable opportunity for examining more ancient skeletal remains, that have long since lost all their soft tissues. A partially moss-covered Thule dog skull (probably about 800 years old) and a partly moss-covered seal skull, believed to be associated with a nearby Dorset long house (probably 1,000 years old), both intensely desiccated, stand on the surface in a state of near collapse. On the higher beach-ridges and screes are seal and other remains associated with Pre-Dorset/Independence activities (some perhaps 3,000 years old) that have been 'planed down' on their outer surfaces - in some instances to only half their original thickness. The remaining parts are nevertheless in robust condition. The cause of this erosion, which may include wind-blasting, is being studied. A preliminary examination of one of the specimens by scanning electron microscope revealed the presence of great numbers of small tetragonal bipyramids of the mineral weddellite (calcium oxalate, $CaC_2O_4 \cdot 2H_2O$) (Figure 4). Jones *et al.* (1980) obtained weddellite crystals in agar jelly beneath a growing colony of the lichen *Pertusaria corallina*: the role of lichens in the breakdown of bone is to be further pursued in this study.

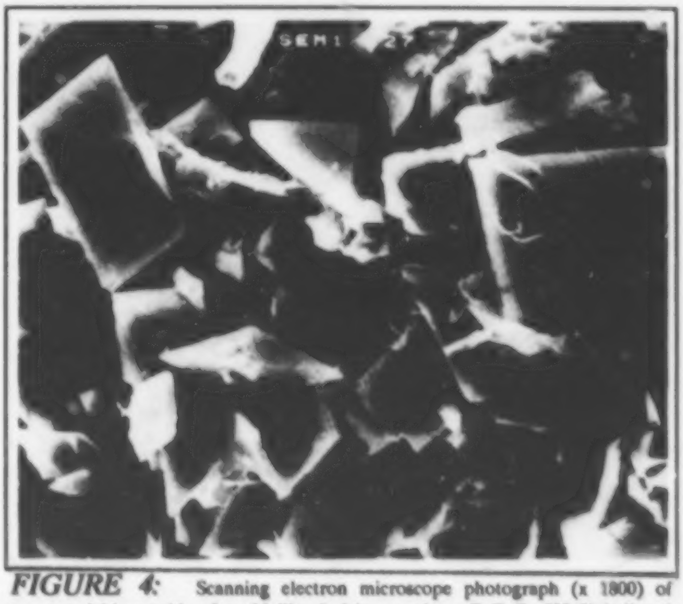


FIGURE 4: Scanning electron microscope photograph (x 1800) of tetragonal bipyramids of weddellite (calcium oxalate, $CaC_2O_4.2H_20$) believed to be a by-product of lichen growth, from a seal bone on the surface of the ground at McGhee's Dorset/Thule site at Brooman Point, Bathurst Island. Photograph courtesy of D. Claugher, British Museum (Natural History).

The extreme aridity of the Brooman Point screes is vividly demonstrated by the condition of the limestone fragments on the arctic desert flat which forms the summit of the peninsula. Some of these show karst-solution features on their upper surfaces, yet underneath they carry botryoidal stalagmitic deposits, suggesting almost immediate re-precipitation of the dissolved limestone before the solution can even percolate into the ground below.

Damp Ground

Where mammalian remains rest on damp ground, decomposition follows a significantly different sequence of events. Where summer thaw allows sufficient warming, rapid algal growth commonly occurs on the moist lower surfaces of such remains (e.g. on the skeleton of a muskox that died in 1967 near the High Arctic Research Station in Polar Bear Pass, examined in 1975 and again in 1979). Even matted masses of hair associated with the skeleton had a green coating of algae. What happens next depends on the proximity of a particular part of the carcass to the ground, and it is common to see an abrupt change in its state of preservation just above ground level - soft parts surviving in the drier zone above long after they have disappeared from the damper zone below. Instructive instances include an associated vertebral column of a muskox and another muskox skull (Figure 1d), both dead only a few decades, at two localities in Polar Bear Pass. Since the vertebral column was bowed, both ends rested on the ground while the central parts stood clear. Already the intervertebral discs at the ends had rotted, allowing the vertebrae to separate from one another, whereas the central part of the column was still intact. The skull lay so that the horns were mainly above ground, although the tip of one horn penetrated the underlying soil. The exposed parts of the horns were fresh, whereas the tip was extensively rotted and penetrated by the roots of herbs.

An important further instance of this sort of preservation is provided by muskox remains collected by Hickey from the *Investigator* site at Mercy Bay, Banks Island. Here, the ground is strewn with many muskox skeletons killed between 1855 and 1890 by Copper Inuit who had arrived from Victoria Island in order to salvage stores from the abandoned Franklin-search vessel, H.M.S. *Investigator*. The rather exact age for these remains makes them especially valuable for this study. The way in which decay has occurred (soft tissues and horns well preserved above ground, but rotted at ground level) closely resembles that observed in the Polar Bear Pass specimens described above, though with greater lichen development on the exposed surfaces (in part at least a reflection of age).

Mammalian remains that are sufficiently large for parts to stand clear of the ground, as in the above examples, are relatively rare. More numerous are smaller specimens that lie in contact with the ground. They are typically little weathered and have algal growth on their lower surfaces, being more weathered and with lichens above (Figure 5).

The way in which walrus ivory decays differs considerably from that of bones. It provides a poorer substrate for lichens, and the most common form of breakdown is by warping and exfoliation of the dentine layers.

Peaty and Other Acid Deposits

Peaty deposits are widespread in boggy areas of the High Arctic, occurring even in areas of alkaline base rocks. The growth of such deposits may lead to the incorporation of mammalian remains, which then become susceptible to acid attack. Instructive instances of this were observed at Eskimobyen and in Polar Bear Pass. In a peaty hollow on granitic bedrock beside Schledermann's Thule house no. 3 at Eskimobyen a walrus femur was found at a depth of 10-15 cm. It showed extensive decay of the spongy ends, whereas the surviving outer parts retained their original resilience. Two caribou bones found on the ground surface in Polar Bear Pass (but which had patches of peat adhering, suggesting that they had been disinterred from peat deposits) were deeply eroded. Their remaining parts were nevertheless in fresh condition up to their surfaces, there being no zonation outwards from fresh to decayed bone.

One instance of root marks (solution of the bone surface by the roots of plants) was observed on a caribou jaw found in damp surroundings with herbaceous plant growth near McGhee's archaeological site OkLg-3 in Polar Bear Pass.

Freshwater Pools

This is a difficult subenvironment to interpret since pools that we see today may be younger than bones lying in them; conversely previously existing pools may have dried up. There is also great variation in the nature of bottom sediment. A clear freshwater lake with a rocky bottom and permanent snowbank along its northeast side (an isostatically raised former marine lagoon) at Brooman Point produced part of a polar bear skull (its canines evidently broken out by Thule people) and some seal bones. These remains were well preserved, though with algal growth on all surfaces. In contrast, (although no bones were found in it) there is on Skraeling Island a freshwater pool with a muddy bottom containing worms surrounded by luxuriant vegetation, including sedges and buttercups.

The Sea Shore

A distinct zone of weathering occurs along the sea shore. Watts (1981), describing the Alexandra Fiord area, mentions intense rock-weathering which he thought resulted from salt-crystallization in postglacial time. Surprisingly, this zone appears to be relatively favourable for the preservation of bone. Although lichens form such an important part of the arctic flora, a narrow lichen-free zone occurs along the shore in parts of the study area (e.g. at Eskimobyen and at the old Police Detachment on Bache Peninsula).

Two well-preserved whale skulls, lying on the beach below the Thule dwellings at Eskimobyen, stand out conspicuously because of their whiteness, and there are many smaller specimens in similar condition scattered along the shore. Some factor (perhaps salt spray?) inhibits lichen growth in this environment, and the bones are better preserved than those of equivalent age only a short distance inland. There is, nevertheless, abundant algal growth on the undersides of the bones of this zone. A well-preserved seal skull of uncertain date, collected at low-water from the intertidal zone of a salt water lagoon at Brooman Point, also had a rich algal growth on its lower surface.

Several instances of bone decay commencing before the final disappearance of soft tissues was observed in this shore environment (e.g. among the remains from Bache Peninsula (1926-1933); and a series of walrus vertebrae of uncertain age, with the intervertebral discs well preserved, from the beach at Eskimobyen).

Near the Dorset long house on Knud Peninsula (named by Schledermann "Cove site"), situated close to the sea but about 9 m above it, is a saline pool surrounded, on recently wet ground, by efflorescences of thenardite sodium sulphate, a widespread mineral in polar regions (Tedrow 1977; Watts 1981). The apparent mineralization of some bones from this site is being investigated.

Other Microenvironments

A block of fused hearth material containing much charred bone, collected from the surface of a raised-beach ridge near a Thule house on Brooman Point cannot be included in any of the above categories. It has yet to be studied.

Although, on first consideration, it might be tempting to regard the raised-beach ridges of such localities as Brooman Point as a microenvironment in their own right, they cannot be so classified. Conditions vary greatly from trough to ridge and between the lower and upper surfaces of bones preserved on them, and each of these zones must be considered separately.

CHRONOLOGICAL CONCLUSIONS

From the observations outlined above, and other data, it now becomes possible to make some generalizations about how long mammalian remains (both soft and skeletal parts) can be expected to survive in the permafrost environment. We have seen that in the permafrost itself soft parts can be preserved almost indefinitely (40,000 years or more in the case of the Pleistocene carcasses from Siberia, Alaska and Yukon), and I will not discuss this zone further. On the ground surface, in contrast, decay will ultimately occur, although it may take thousands of years. An important factor contributing to slowing this process is the shortness of the summer, when such remains are snow-free for only about two months in most of the study area, and the long winter, when the ground is frozen up to the surface together with all the remains lying on it.

The way in which this winter-freeze halts the decay of mammalian remains is well illustrated by the frozen carcass of a juvenile arctic fox, newly exposed by melting snow during the later-than-usual summer thaw in Polar Bear Pass, on 3 July 1979. The fox still had its grey summer pelage from the previous year, suggesting that it had died during the first winter snowfall, not later than about September 1978 - a period of 9-10 months frozen in the snow. Decay during this time appeared to have been halted, even the eyes having the appearance of an animal newly dead. The carcass disappeared the following day, presumably removed by a scavenger.

The speedy disappearance of this carcass vividly demonstrates the potential for destruction of such remains shortly after the death of the animals concerned, so that only a proportion of them survive into a regime of long-term preservation. Some carcass material is removed almost at once by carnivores (of which wolves are the most powerful bone-breakers in the study area) for quick return to the lithosphere via the droppings of the animals concerned.

Much other material survives. Probably the most important factor influencing this is the object's size. Most parts of whale skeletons are too large for destruction by wolves, although these animals, hunting in packs, can kill muskoxen (Gray 1987) and heavily damage their skeletal remains. Only skulls, vertebrae (especially cervical vertebrae), adult limb bones, metapodials and other robust parts are likely to survive their ravages. Wolves can break caribou bones into small splinters. Bone fragments swallowed by wolves reappear in their droppings, apparently unaltered.

Arctic foxes may cause minor secondary damage to bones of animals killed by wolves and polar bears. I assume that, since the foxes scavenge around camps now, they also scavenged around early Inuit sites at the time of their occupation. Arctic foxes also remove carcasses of lemmings and birds from the environment by eating them.

Caribou are potential destroyers of shed antlers and bones which, in other regions, they have been known to chew to destruction (Sutcliffe 1977).

Remarkably, the consumption of lemmings by Snowy Owls leads to the potentially longer survival of their skeletal remains than if they had died in the open, since bones packed in pellet hair-masses (which occur in great quantity around roosting hummocks) cannot begin to decompose until exposed by the dispersal of this hair, which may take some time.

When all these factors are considered it is immediately apparent that far more skeletal material is preserved in the study area than would be expected in a region of so much carnivore activity. In Zimbabwe, Haynes (1988) has recorded that when other food sources fail, spotted hyaenas return to the bones of elephants that have been dead for some time. Although the analogy of hyaena and wolf feeding-habits is not close, it might be expected that the conditions of natural refrigeration prevailing in the arctic would make it worthwhile for the carnivores there to return to old carcasses for a much longer period than they do in lower latitudes. But this is apparently no so. Although regular inspection of carcass remains by wolves and foxes continues for a long time (personal communication, S.D. MacDonald), there seems to be an early cut off point, after which no further damage occurs. Examples of remains surviving in a more complete condition than might be expected include: carcasses of two muskoxen that died in Polar Bear Pass (one before 1968, the other in 1967), which were extensively splintered and chewed by wolves when fresh but untouched during the study period 1975-1979; splinters of caribou bone, previously mentioned, associated with McGhee's archaeological site OkLg-3, untouched by carnivores, although situated only 200 m from an active arctic fox den; and diverse complete naturally-shed caribou antlers, especially in Polar Bear Pass - some almost obscured by mosses. This cut off point seems to have a significant place in the bone-decay sequence of the Canadian High Arctic, following which further breakdown is related only to local microenvironmental factors.

In conclusion let us try to establish a chronology for subsequent stages of decay. Since rates vary locally, according to microenvironmental conditions, no simple generalization can be made. The simplest approach is to record the longest time that the various parts of carcasses can survive under the most favourable conditions. There is a substantial amount of data.

We have seen that bones usually survive longer than the soft tissues on them, although it is not unusual for bone decay to commence before the disappearance of the last of these on the more protected parts of the same bones. Soft parts more than a century old are not uncommon, for example on the Mercy Bay muskox remains dating from the period 1855-1890. A small remnant of cartilage on a walrus vertebra from Eskimobyen, believed to be associated with the Thule occupation of that locality, may be substantially older than this, but in general it seems unlikely that much in the way of soft tissue has survived on bones lying on the ground surface for longer than about 250 years.

Although soft tissues tend to be relatively short-lived, the remaining skeletal parts probably survive for a very long time. Four examples of long-term preservation, in order of increasing age follow.

(1) A Thule snow knife from Brooman Point (Figure 5). It is believed to be about 800 years old and to have lain undisturbed on the ground throughout that time. There is substantial lichen growth and some decay above, and better preservation and algal growth below.

(2) A series of seal jaws from the ground surface on Knud Peninsula, believed to be associated with a nearby Late Dorset long house (Schledermann's site SgFm-3) about 1,000 years old, show similar preservational variations, but with more advanced decay, including flaking, on the upper surfaces.

(3) A walrus-ivory harpoon head of Independence Culture I age, more than 3,500 years old, from a flat area of limestone fragments on the hill slope above McGhee's excavation

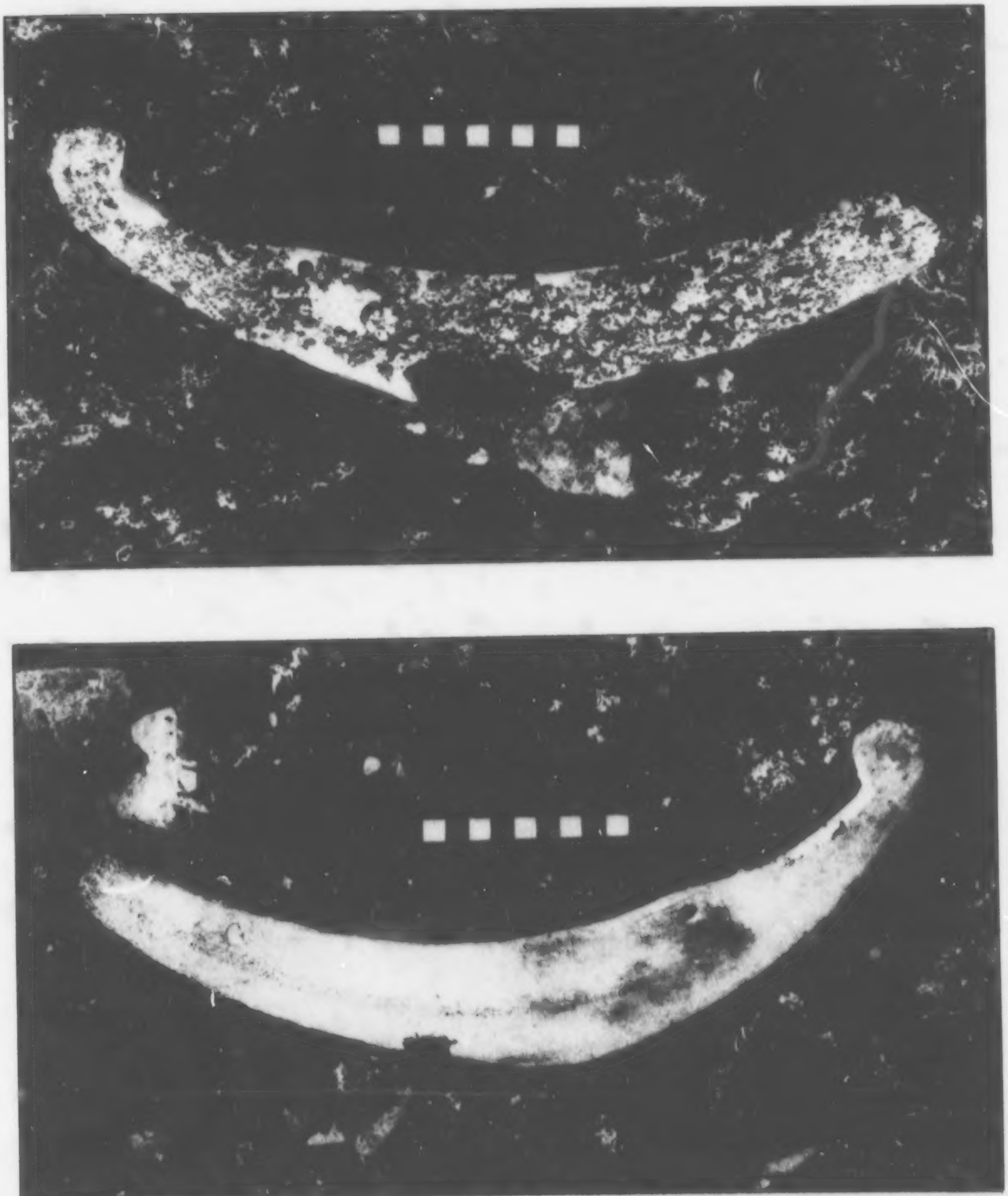


FIGURE 5: Thule snow knife, believed to have been undisturbed for 800 years, on the ground surface at McGhee's excavation site at Brooman Point, Bathurst Island, 1979. (a) in situ, substantial lichen growth on upper surface, (b) specimen turned over to show fresh condition of lower surface.

sites at Brooman Point. It was noticed only because of its moss cover. It is very well preserved.

(4) Remains from the raised beaches. The earliest Inuit sites in the Canadian High Arctic Islands are only about 4,000 years old, so that archaeological evidence cannot be applied to bone studies earlier than this. It is nevertheless fortunate that a great quantity of mammalian remains is available (mostly of whales, associated with raised-beach ridges that are so widespread in the area), which allows the study to reach back to about 9,000 years ago. Before this much of the area was glaciated.

Studies of these flights of beach ridges by Blake and others, using radiocarbon dating of associated driftwood, mollusc shells and whale bones, and involving studies of drifted pumice (Blake 1970, 1975, as well as individual radiocarbon dates published regularly in the Geological Survey of Canada Radiocarbon Dates) provide a detailed record of postglacial isostatic emergence in the Canadian Arctic Islands and, with it, an accurate chronological basis for studying rates of decay of the associated skeletal material - the youngest of which overlaps in time with the archaeological record.

At Cape Storm, southern Ellesmere Island (an area of especially great isostatic uplift), Blake (1975) found that postglacial marine features extended up to 130 m above sea level; emergence between 9,000 and 8,000 years ago having proceeded at 7 m a century, slowing to 0.8 m between 6,500 and 4,500 years ago and less than 0.3 m for the last 2,400 years. He found that whale bones were scattered about at many levels between the present shore and the limit of marine submergence. Some of these were frozen into the ground, others were exposed on the surface where their presence was indicated by vegetation. There were instances of lemmings using hollow parts of bones, above the frost table, as burrows. One of the oldest whale-bone samples collected from Cape Storm, at an elevation of 118 m (Blake 1979), gave an uncorrected radiocarbon date, based on six determinations, of between 8,770 and 9,600 years.

I saw only one raised-beach specimen *in situ*, an undated skull of a bowhead whale in Polar Bear Pass (Figure 6). This and other raised-beach specimens observed from other localities are mostly in a remarkable state of preservation. The 9,000 year limit, where this study must close due to paucity of earlier surface-remains, does not mark the potential survival limit for bones in this environment of the Canadian High Arctic.

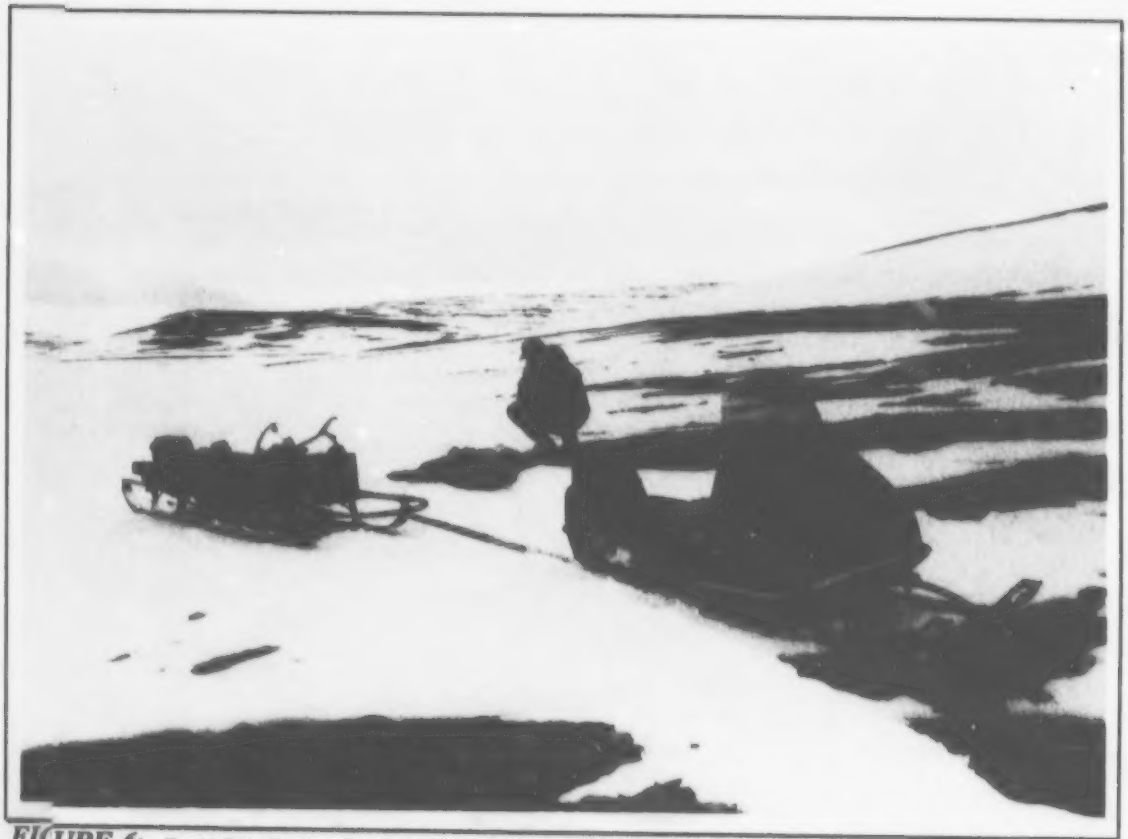


FIGURE 6: David Gill (Zoology Division, National Museum of Natural Sciences) inspects a partly-buried skull of a bowhead whale (undated, possibly as old as 9,000 years) on a raised-beach ridge now 6 km from the sea, in Polar Bear Pass, Bathurst Island, June 1979. Although the skull is damaged, the constituent bone is still fresh.

FUTURE WORK

This study of the rates of decay of carcass remains in the permafrost environment is still at an early stage. The program of investigation of microstructure by scanning electron microscope, already commenced, is being extended with special attention to the effects of lichen and algal growth and to secondary mineralization. There are many instances of bones which, although on visual inspection appear to be extensively decayed, have a fresh core or are made up of entirely fresh fragments, commonly with lichen growth between them. There already exists much literature on rock-weathering, including salt-weathering, in the Arctic (Blake 1978; Watts 1979, 1981) that has not yet been explored in this study, despite the fact that it has great relevance.

The role of microenvironmental influence on bone decay needs to be investigated in greater detail in the field; and the study should be extended to the Middle and Low Arctic.

REFERENCES

Anthony, H.E. 1949. Nature's deep freeze. Natural History 58:296-301.

Beattie, O. and J. Geiger. 1987. Frozen in time. Bloomsbury, London. 180 pp.

Blake, W., Jr. 1970. Studies of glacial history of Arctic Canada. I. Canadian Journal of Earth Sciences 7:634-664.

______. 1975. Radiocarbon age determinations and postglacial emergence at Cape Storm, southern Ellesmere Island, Arctic Canada. Geografiska Annaler 57A:1-71.

______. 1978. Rock weathering forms above Cory Glacier, Ellesmere Island, District of Franklin. Geological Survey of Canada, Paper 78-1B:207-211.

______. 1979. [Radiocarbon dates from Cape Storm, Ellesmere Island]. Geological Survey of Canada, Paper 79-7:42-43.

Bliss, L.C. (Editor). 1977. Truelove Lowland, Devon Island, Canada: a High Arctic ecosystem. University of Alberta Press, Edmonton. 714 pp.

Dekin, A.D. 1987. Sealed in time. National Geographic Magazine 171:824-836.

Dineley, D.L. and P.A. Garrett. 1959. Whale remains in glacier ice. Nature 183:272.

Dort, W., Jr. 1975. Significance and antiquity of mummified seals in southern Victoria Land, Antarctica. Biology of the seal. Proceedings of a symposium held in Guelph (August 14-17, 1972). Rapports et Procès-verbaux des Réunions Conseil International pour l'Exploration de la Mer. 169:57-69.

Garutt, W.E. 1964. Das Mammut. Die neue Brehm-Bucherei, Stuttgart, Kosmos Verlag.

Glob, P.V. 1973. The bog people. Paladin, St. Albans. 142 pp.

Gray, D.R. 1987. The muskoxen of Polar Bear Pass. Fitzhenry and Whiteside, Markham, Ontario. 191 pp.

Greely, A.W. 1886. Three years of arctic service. 2 volumes. Richard Bentley and Son, London. 428 pp., 444 pp.

Grunin, K. Ya. 1973. Pervaya nakhodka lichinok zheludochnogo ovoda mamonta - Cobboldia (Mamontia, Subgen. N.) Russanovi, Sp. N. (Diptera, Gasterophilidae). (The first finding of the stomach bot-fly of the mammoth). Entomologicheskoe obozrenie 52:228-233. (In Russian. English translation in Entomological Revue, Washington, same volume number).

Guthrie, R.D. 1972. Recreating a vanished world. National Geographic Magazine 141:294-301.

______. 1973. Mummified pika (*Ochotona*) carcass and dung pellets from interior Alaska. Journal of Mammalogy 54:970-971.

Hansen, J.P., J. Meldgaard, and J. Nordquist. 1985. The mummies of Qilakitsoq. National Geographic Magazine 167:190-207.

Harington, C.R. 1978. Quaternary vertebrate faunas of Canada and Alaska and their suggested chronological sequence. Syllogeus 15:1-105.

______. 1984. Quaternary marine and land mammals and their paleoenvironmental implications - some examples from northern North America. Carnegie Museum of Natural History, Special Publication No. 8:511-525.

Haynes, G. 1988. Longitudinal studies of African elephant death and bone deposits. Journal of Archaeological Studies 15:131-157.

Jones, D., M.J. Wilson, and J.M. Tait. 1980. Weathering of basalt of *Pertusaria corallina*. Lichenologist 12:277-289.

Lazarev, P. 1977. Novaya nakhodka skeleta sherstistogo nosoroga v Yakutii (New discovery of the skeleton of a woolly rhinoceros in Yakutia.) Trudy zoologicheskogo instituta A.N. S.S.S.R. 63:281-285.

McDonald, J.N. 1984. An extinct muskox mummy from near Fairbanks, Alaska: a progress report. Biological Papers of the University of Alaska, Special Report 4:148-152.

McGhee, R. 1978. Canadian arctic prehistory. National Museum of Man, Ottawa. 128 pp.

______. 1980. Archaeology of the Eskimos. Popular Archaeology 2:20-23.

______. 1981. A tale of two cultures: a prehistoric village in the Canadian Arctic. Archaeology (July-August):44-51.

______. 1984A. Signs and symbols of an ancient people. The Dorset Eskimos of Brooman Point. Oracle (National Museums of Canada) 52:1-4.

______. 1984B. The Thule village at Brooman Point, Arctic Canada. Paper of the Archaeological Survey of Canada, Paper 125:1-158.

McIntyre, L. 1973. The lost empire of the Incas. National Geographic Magazine 144:729-787.

Nares, G.S. 1878. Narrative of a voyage to the Polar Sea during 1875-6. 2 volumes., Sampson Low, London. 395 pp., 378 pp.

Nowak, J., E. Panow, J. Tokarski, W. Szafer, and J. Stach. 1930. The second woolly rhinoceros from Starunia, Poland. Bulletin de l'Académie Polonaise des Sciences et des Lettres. Cracovie. (B) 1930, Supplement. 47 pp.

Parfitt, S. (in preparation). Taphonomy of a recent archaeological bone assemblage from Banks Island, Northwest Territories, Canada. Unpublished undergraduate thesis, London University, Institute of Archaeology.

Péwé, T.L. 1969. The periglacial environment. In: The Periglacial Environment. Edited by: T.L. Péwé. McGill-Queen's University, Montreal. 487 pp.

______. 1975. Quaternary geology of Alaska. U.S. Geological Survey, Professional Paper 835:1-145.

Pfizenmayer, E.W. 1939. Siberian man and mammoth. Blackie and Son, London. (First published in German in 1926).

Powell, T. 1961. The long rescue. W.A. Allen, London. 303 pp.

Schledermann, P. 1978. Preliminary results of archaeological investigations in the Bache Peninsula region, Ellesmere Island, N.W.T. Arctic 31:459-474.

______. 1981. Eskimo and Viking finds in the High Arctic. National Geographic Magazine 159:574-601.

Shilo, N.A. *et al.* 1983. Kirgilyakhskii mamont. (The Kirgilyakh mammoth). Nauka, Moskva. 216 pp. (In Russian).

Skarlato, A. (Editor). 1977. Faune i flora antropogena severo-vostoka Sibiri. (Fauna and flora of the Anthropogene of northeastern Siberia). Trudy zoologicheskogo instituta 63:1-296. (In Russian).

Sokolov, V.E. (Editor). 1982. Yuribeiskii mamont. (The Yuribei mammoth). Nauka, Moskva. 160 pp. (In Russian).

Stefansson, V. 1921. The friendly arctic. MacMillan and Co., London. 784 pp.

Sutcliffe, A.J. 1973. Similarity of bones and antlers chewed by deer to human artifacts. Nature 246:428-430.

______. 1977. Further notes on bones and antlers chewed by deer and other ungulates. Deer 4:73-82.

______. 1985. On the track of Ice Age mammals. British Museum (Natural History), London, and Harvard University Press, Cambridge, Massachusetts. 224 pp.

Sverdrup, O. 1904. New Land. Four years in the arctic regions. 2 volumes, Longmans, Green & Co., London. 496 pp., 504 pp.

Tedrow, C.F. 1977. Soils of the polar landscapes. Rutgers University Press, New Brunswick, New Jersey. 638 pp.

Vereshchagin, N.K. 1974. The mammoth "cemeteries" of north-east Siberia. Polar Record 17 (106):3-12.

______. 1977. Berelekhskoe "kladbishche" mamontov. (Berelekh "cemetery" of mammoths). Trudy zoologicheskogo instituta A.N. S.S.S.R. 72:5-50. (In Russian).

______. 1982. Novaya gydanskaya (yuribeiskaya) nakhodka mamonta. (New Gydansk (Yuribei) discovery of a mammoth). Vestnik zoologii, Kiev 3:32-38. (In Russian).

Vereshchagin, N.K. and V.M. Mikhelson. (Editors). 1981. Magadanskii mamontenok. (The Magadan baby mammoth). Nauka, Leningrad. 296 pp. (In Russian).

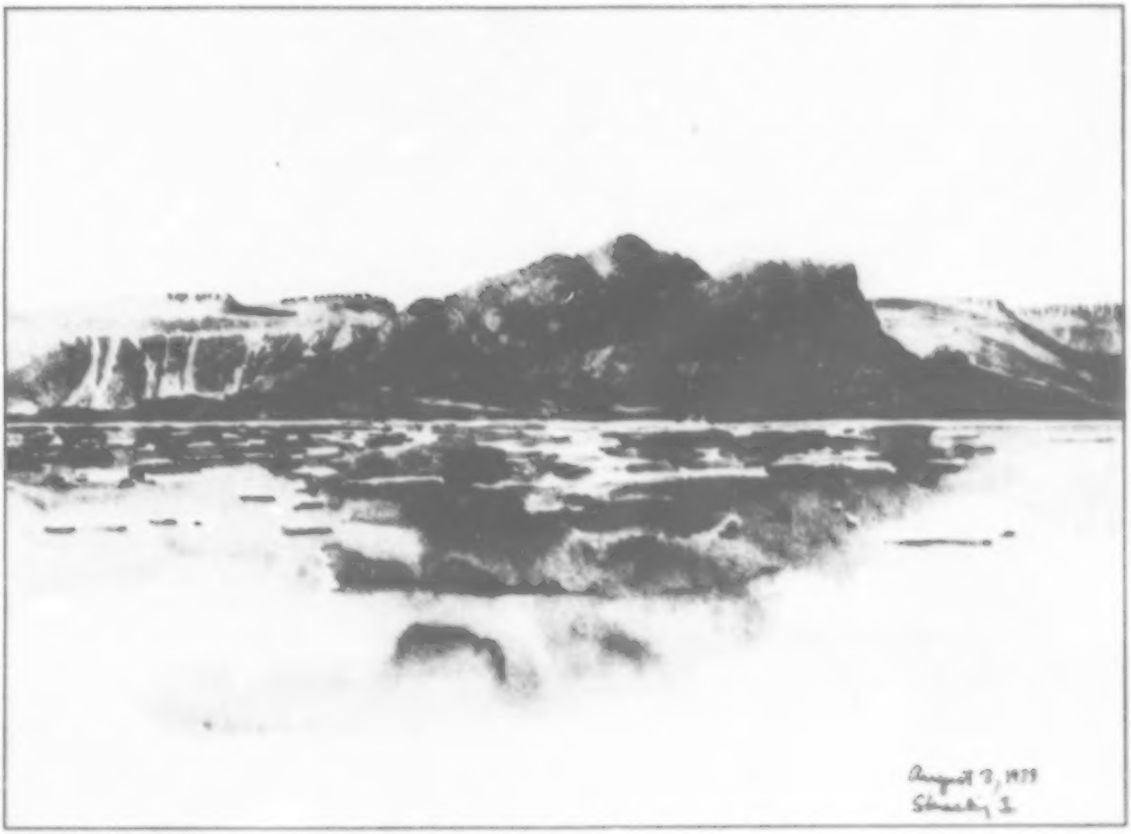
Vinogradov, B.S. 1948. O nakhozhdenii trupov iskopaemykh suslikov v vechnoi merzlote basseina R. Indigirki. (On the discovery of fossil susliks in permafrost in the Indigirka Basin). Doklady Akademii Nauk SSSR 62:553-556.

Watts, S.H. 1979. Some observations on rock weathering, Cumberland Peninsula, Baffin Island. Canadian Journal of Earth Sciences 16:977-983.

Watts, S.H. 1981. Near-coastal weathering features in the Alexandra Fiord area Ellesmere Island, District of Franklin, Canada. Geological Survey of Canada, Paper 81-1A:389-394.

Wilkinson, P.F. and C.C. Shank. 1975. Archaeological observations in north-central Banks Island. Arctic Anthropology 12:104-112.

Youngman, P.M. 1987. Freeze-dried mummies are hot items with paleontologists. BIOME 7(2):4.



Illustrated by Brenda Carter

FRESHWATER, SEA AND ICE

A UNIQUE LAKE IN CANADA'S HIGH ARCTIC

M. Dickman[1], A.G. Lewkowicz[2], and J. Price[3]

Abstract: Garrow Lake, on the southern tip of Little Cornwallis Island, is unique in a number of ways. It displays mid-water temperatures, attributed to solar heating, that are higher than any other arctic lake described to date. Bottom-water salinities in Garrow Lake are two and a third times those of sea water. These properties have stimulated considerable research on the lake and have given rise to a series of hypotheses to account for its hypersalinity in an area where salt domes do not occur.

Solute rejection during ground-freezing associated with isostatic rebound was hypothesized as the major factor contributing to the high salinities in the bottom of Garrow Lake. This mechanism is based on the intrusion of brines through a permafrost-free talik near the lake's centre. This hypothesis was supported by lake-temperature profiles (1980-1987) and theoretical estimates of the depth of soil temperatures beneath the centre of Garrow Lake based on temperature profiles for the nearby Polaris lead and zinc mine. A new mechanism for multiple-thermocline formation and dissolved-oxygen supersaturation was also displayed in Garrow Lake during years when ice-out failed to occur or was incomplete. During these periods, only the top 5 m of water in the lake mixed, and dissolved oxygen from freezing-out processes accumulated in the 5-10 m deep layer within the lake.

Résumé: Le lac Garrow, sur la pointe sud de la petite île de Cornwallis, est unique de bien des manières. La température de l'eau à mi-niveau, fonction du réchauffement solaire, y est plus élevée que dans tout autre lac de l'Arctique décrit jusqu'à maintenant. La salinité de l'eau du fond du lac Garrow est deux fois et un tiers celle de l'eau de mer. Ces propriétés ont suscité beaucoup de recherches sur le lac, ainsi qu'une série d'hypothèses tentant d'expliquer cette hypersalinité dans une région où on ne rencontre pas de dôme de sel.

On a envisagé que le rejet de la solution pendant le gel du sol, associé à la remontée isostatique, soit un facteur important de la salinité élevée dans le fond du lac Garrow. Ce mécanisme repose sur l'instrusion d'eau salée á travers un talik vers le centre du lac. Cette hypothèse est étayée par les profils de température du lac (1980-1987) et les évaluations théoriques des températures du sol en profondeur sous le centre du lac Garrow reposant sur les profils de température de la mine de plomb et de zinc Polaris, située á proxmité. Un nouveau mécanisme de formation de thermoclines multiples et de sursaturation d'oxygène dissout s'est aussi manifesté dans le lac Garrow pendant les années au cours desquelles le déglacement ne s'est pas fait ou a été incomplet. Pendant ces périodes, seuls les 5 m d'eau les plus proches de la surface se sont mélangés et ont dissout l'oxygène provenant de l'englacement et accumulé dans la couche de 5 à 10 m de profondeur à l'intérieur du lac.

INTRODUCTION

Density-stratified High Arctic lakes have been reported for Greenland (Trolle 1913), the Mackenzie Delta (Kovio and Ritchie 1978), Ellesmere Island (Hattersley-Smith *et al.* 1970), Cornwallis Island (Page *et al.* 1987); Ouellet *et al.* 1987) and Little Cornwallis Island (Dickman and Ouellet 1983, 1987). The salinity in the bottom (monimolimnia) of these meromictic (permanently-stratified) lakes is less than that of sea water with the exception of: (1) Sophia Lake (75°06'N, 93°31'W) on Cornwallis Island, N.W.T. with a maximum salinity of 50 g/l; and (2) Garrow Lake (75°23'N, 96°50'W) on Little Cornwallis Island, N.W.T. with a maximum salinity of 82 g/l. Because of their unusual characteristics, these two hypersaline lakes have been the focus of considerable limnological study (Dickman and Ouellet 1983;

---

[1] Biological Sciences Department, Brock University, St. Catherines, Ontario L2S 3A1
[2] Geography Department, Erindale College, University of Toronto, Mississauga, Ontario L5L 1C6
[3] Geography Department, McMaster University, Hamilton, Ontario L8S 4K1

Pagé *et al.* 1984, 1987; Stewart and Platford, 1986; Ouellet *et al.* 1987; Dickman and Ouellet 1987). Several mechanisms drawn from Antarctic work (e.g., Goldman 1970; Harris and Cartwright 1981) have been suggested as explanations for the ontogeny of polar lake hypersalinity. These various hypotheses have concentrated on the process of salinity generation via the "freezing-out" process (Stewart and Platford 1986).

The aim of this paper is to present additional evidence relating to the solute rejection of brines during ground-freezing associated with isostatic rebound. This mechanism is based on the notion of intrusion of brines through a permafrost-free "talik" or chimney near the centre of Garrow Lake. A third possible source of the hypersalinity in Garrow Lake is seasonal groundwater-flow from the active layer. Furthermore, certain aspects of the limnology of Garrow Lake are newly identified.

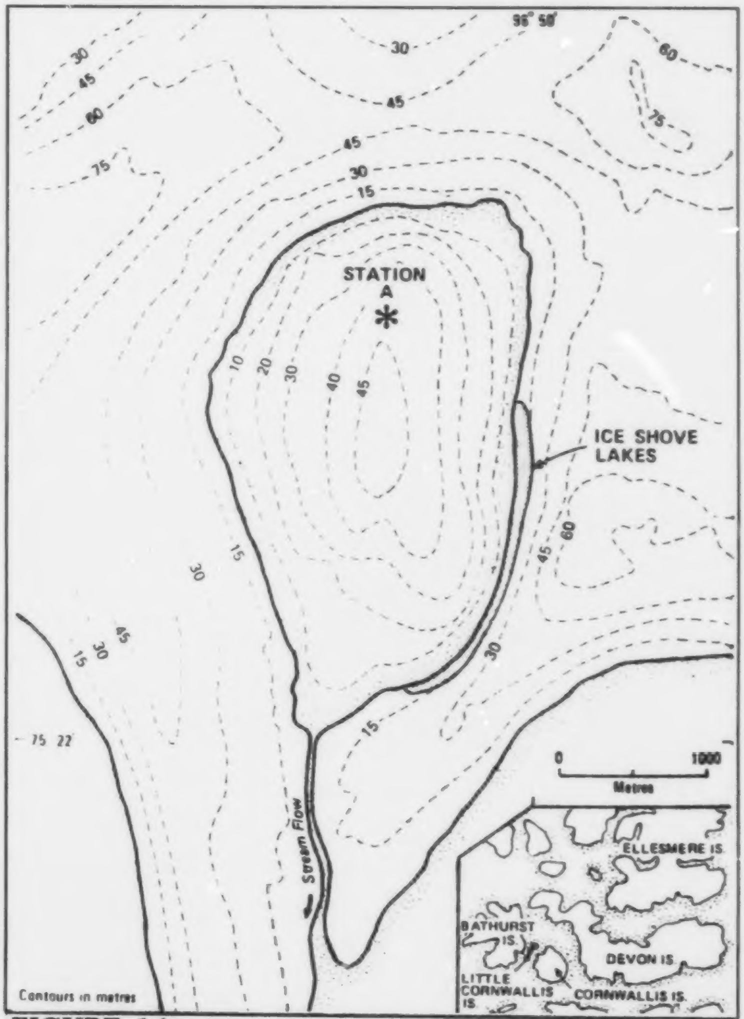

96° 58'
30
45
60
75
30
45
45
30
15
60
75
STATION
A
10
20
30
40
45
ICE SHOVE
LAKES
15
30
60
45
30
15
45
30
15
75 22
Stream Flow
0
1000
Metres
Contours in metres
ELLESMERE IS.
BATHURST
IS.
DEVON IS.
LITTLE
CORNWALLIS
IS.
CORNWALLIS IS.

FIGURE 1A: Morphometric map of Garrow Lake, Little Cornwallis Island, N.W.T. with inset of Devon, Little Cornwallis, Bathurst and Ellesmere islands. Details of the Polaris Mine Area were provided by Energy Mines and Resources Canada's Riddle Point NTS map No. 68H-8.

LAKE DESCRIPTION

Garrow Lake (Figures 1A-C), located in the High Arctic on the southern tip of Little Cornwallis Island approximately 95 km from Resolute, N.W.T., is the most northerly hypersaline lake known in the world. It has an area of 418 ha, a

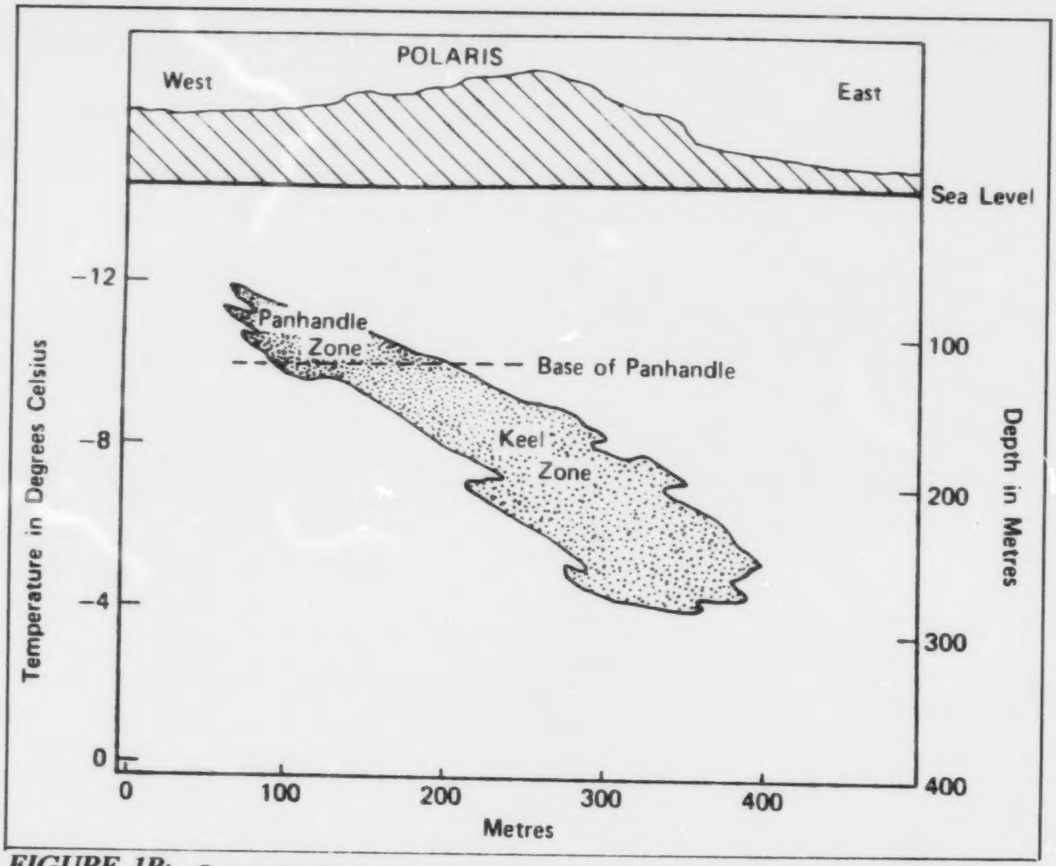

POLARIS
West
East
Sea Level
Panhandle Zone
Base of Panhandle
Keel Zone
Temperature in Degrees Celsius
-12
-8
-4
0
Depth in Metres
100
200
300
400
0
100
200
300
400
Metres

FIGURE 1B: Cross section through the main portion of the lead and zinc ore body at Polaris Mine was based on figures provided by Drake (1984).

maximum depth of 47 m, and is covered by ice (to a maximum thickness of 2.2 m) for more than 11 months of the year. The profundal-zone salinity of this ultraoligotrophic meromictic lake is 75 parts per thousand. This is nearly two and a half times the salinity of sea water. As a result of this high salinity, the dense saline layer of water at 20 m in Garrow Lake traps sunlight and converts it into heat (mean annual temperature at 20 m = 9.1°C) or into chemical energy via photosynthesis (a dense population of phototrophic bacteria have colonized the anaerobic chemocline at 20 m in Garrow Lake (Dickman and Ouellet 1987)).

Because the salinity and hence the density of the water at the chemocline in Garrow Lake are so high, substantial solar-warming can be induced without the density of the water increasing to the point at which mixing with the overlying water masses can occur. As a result, Garrow Lake's chemocline is a significant heat sink. To the best of our knowledge, no other solar lake in the Canadian Arctic maintains such high winter temperatures. Thus, in a part of the world where the mean annual air temperature is -16.6°C (Anonymous 1982), the water at 20 m in Garrow Lake ranges between 8.9 and 9.1°C. Solar lakes have been discussed for temperate (Cohen *et al.* 1977) and Antarctic areas (Goldman 1970; Harris *et al.* 1979; Harris and Cartwright 1981; Heywood 1977) but this is the first publication on one in the Arctic.

METHODS

Chemistry

Garrow Lake was sampled during August 1980, 1981, 1982, June 1984 and August 1987. All water samples were taken using a 2 litre Van Dorn bottle and transferred to new half litre Nalgene plastic bottles which had been twice rinsed in the water with which they were filled.

Dissolved oxygen, pH, temperature and specific conductivity and salinity were measured in the field using a Hydrolab 4000 and/or a Y.S.I. conductivity meter (model 51A) and a Y.S.I. dissolved oxygen meter (model 33).

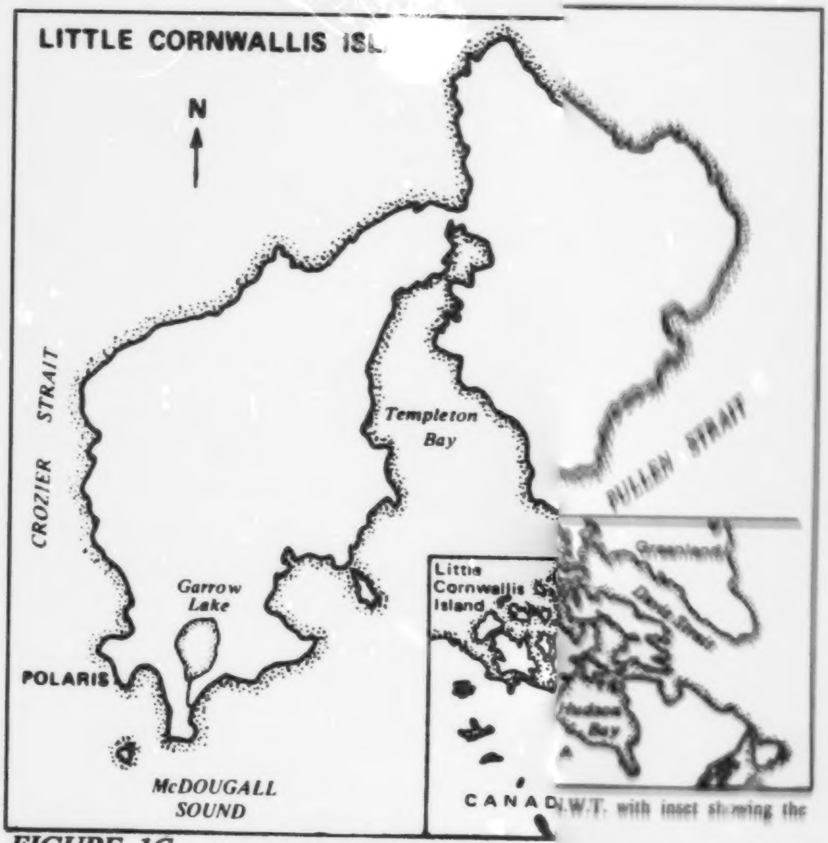

LITTLE CORNWALLIS ISL
N
CROZIER STRAIT
Templeton Bay
PULLEN STRAIT
Garrow Lake
POLARIS
McDOUGALL SOUND
Little Cornwallis Island
Greenland
Davis Strait
Hudson Bay
CANADA

FIGURE 1C: Garrow Lake, Little Cornwallis Island, N.W.T. with inset showing the position of Little Cornwallis Island in relation to Arctic Canada

Major ions analyzed by INRS-Eau in St. Foy, Quebec and by Canada Centre for Inland Waters in Burlington, Ontario have been published elsewhere (Stewart and Platford

1986; Dickman and Ouellet 1987; Ouellet *et al.* 1987). Analytical methods used in the laboratory are described by Pagé *et al.* (1984).

Active Layer Analyses

To estimate the salinity of the seasonally-thawed active layer of soil surrounding Garrow Lake, soil cores retrieved on 20 August 1987 were analyzed. The cores were cut into sections and oven dried at 90°C, weighed, dispersed in a measured volume of deionized water for 24 hours and stirred frequently. Supernatant chlorinity was measured with an Orion combination chloride electrode, and the values converted to mg of chloride per gram of soil (C_s). Pore-water chlorinity (C_w) was estimated as $C_w = C_s\ Pb/n$, where soil bulk density (P_b) and porosity (n) were assumed to be 1,650 kg/m^3 and 0.3 respectively.

RESULTS

Evidence for a Throughgoing Talik in Garrow Lake

Those arguing that Garrow Lake was injected with saline brines as the Little Cornwallis Island mass rose out of the sea (isostatic rebound) assume the presence of a permafrost-free "talik", or chimney, near the centre of the lake (Dickman and Ouellet 1983; Pagé *et al.* 1984, 1987). In this paper we attempt to provide additional evidence for the talik hypothesis. To test the hypothesis that a talik exists below Garrow Lake, we assembled all of the temperature profiles for 1980-1987 (Figure 2). In addition, the salinity, specific conductivity and dissolved oxygen depth profiles (Figures 3-5) were studied for evidence of convective mixing.

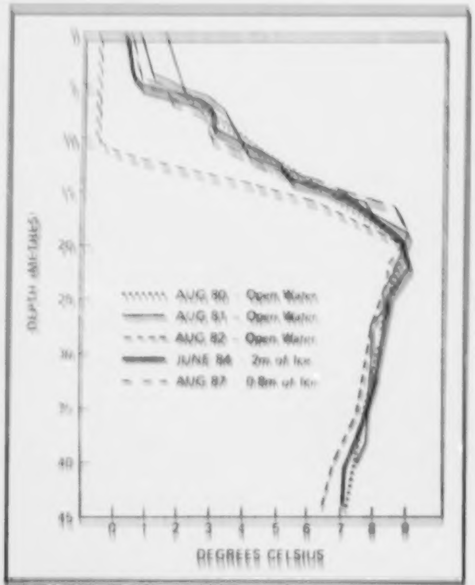


FIGURE 2: Vertical temperature profile for Garrow Lake (1980-87). Except for August, 1982 when the lake was mixing to 10 m, the lake displayed multiple thermoclines at 5 m and 9-17 m. Temperatures were always highest at 19-20 m (8.9-9.1°C) and always decreased to 6.5-7.1°C at the bottom of the lake.

Figure 6 presents a number of predictions for ground temperatures beneath Garrow Lake based on varying the estimated mean ground surface temperature and the local geothermal gradient. This was carried out using the following equation (modified from Mackay 1962):

$$[1]\quad T_Z = T_L + Z(*I) - Z(T_L - T_S - (D*I))/\surd Z^2 + R^2$$

where T_Z is the ground temperature (°C) at a depth Z (m) below the bottom of the lake; T_L is the mean annual lake-bottom temperature (°C); I is the geothermal gradient (°C/m); T_S is the mean annual ground-surface temperature (°C); D is the depth of the lake (m).

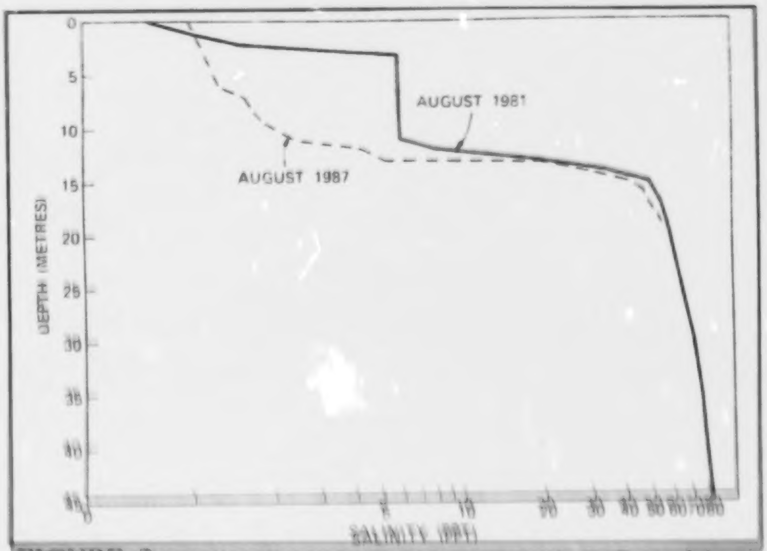


FIGURE 3. Vertical salinity profiles for the deepest point in Garrow Lake on August 1981 and from 20 m of water on 22 August 1987 (log scale used).

The mean annual air temperature at nearby Resolute Bay on Cornwallis Island is -16.6°C (Anonymous 1982) and the mean surface temperature is likely to be slightly warmer (Brown 1972), due primarily to the insulating properties of the winter snow-cover. The temperature of the subterranean sediments were reported by Drake (1984) for the nearby Polaris orebody, which lies near the top of the Thumb Mountain Formation (Figure 1B). At a depth of 400 m below sea level, the temperature of the dolomite, calcite and marcasite, the dominant minerals of Thumb Mountain Formation, approaches 0°C (Drake 1984).

Simulations were run with a conservative value for T_S of -16°C and a more realistic value of -14°C. The minimum radius of Garrow Lake is 900 m and this was used throughout as was a depth of 45 m, providing conservatively low temperatures. The geothermal gradient was initially set at 0.042°C/m, based on a permafrost thickness of 390 m at the Polaris Mine (Drake 1984). According to these calculations (Figure 6, lines A,B),

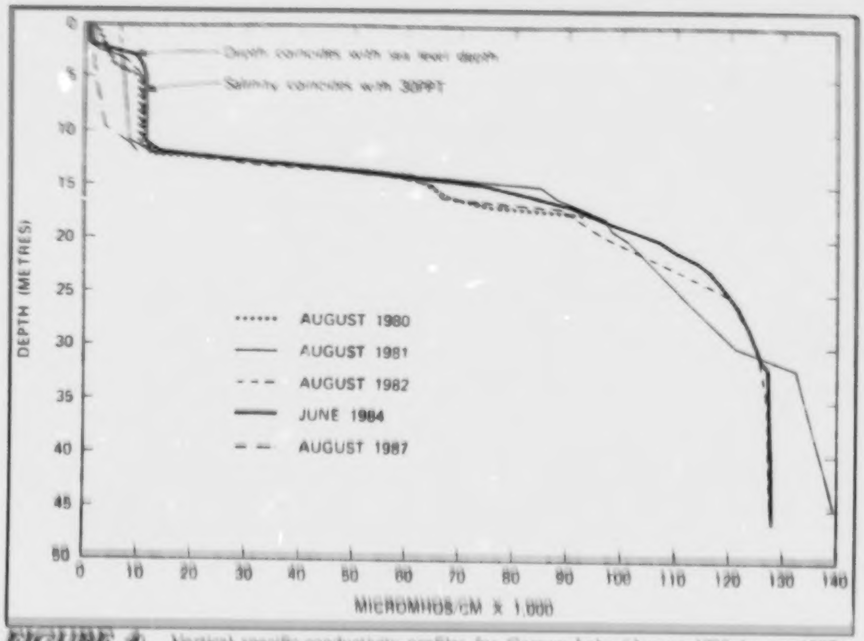


FIGURE 4: Vertical specific-conductivity profiles for Garrow Lake (August 1980-August 1987).

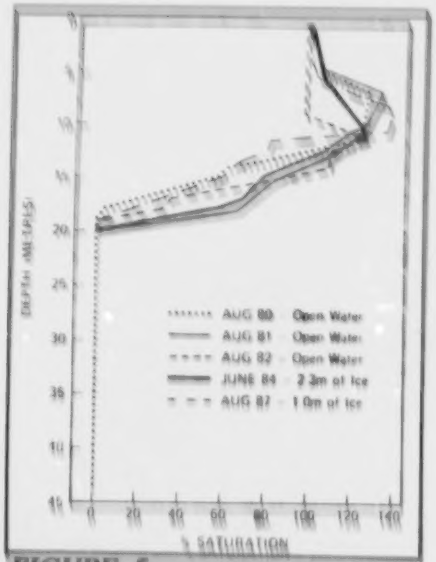


FIGURE 5: Percent saturation (dissolved oxygen) in Garrow Lake (August 1980 - August 1987).

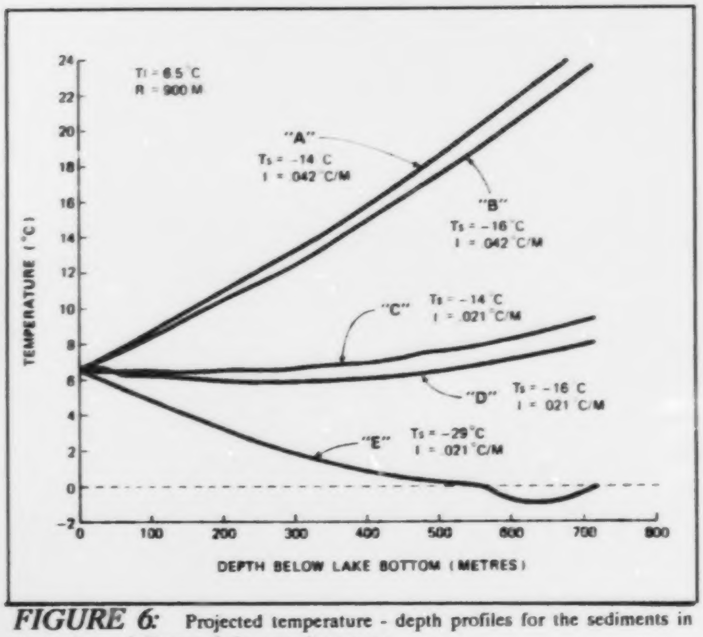


FIGURE 6: Projected temperature - depth profiles for the sediments in the bottom of Garrow Lake near its centre.

A. = mean surface temperature of -14°C and geothermal gradient X 1.0 (results in a throughgoing talik)
B. = mean surface temperature of -16°C and geothermal gradient X 1.0 (results in a throughgoing talik)
C. = mean surface temperature of -14°C and geothermal gradient X 0.5 (results in a throughgoing talik)
D. = mean surface temperature of -16°C and geothermal gradient X 0.5 (results in a throughgoing talik)
E. = mean surface temperature of -29°C and geothermal gradient X 1.0 (fails to result in a throughgoing talik. See text for explanation)

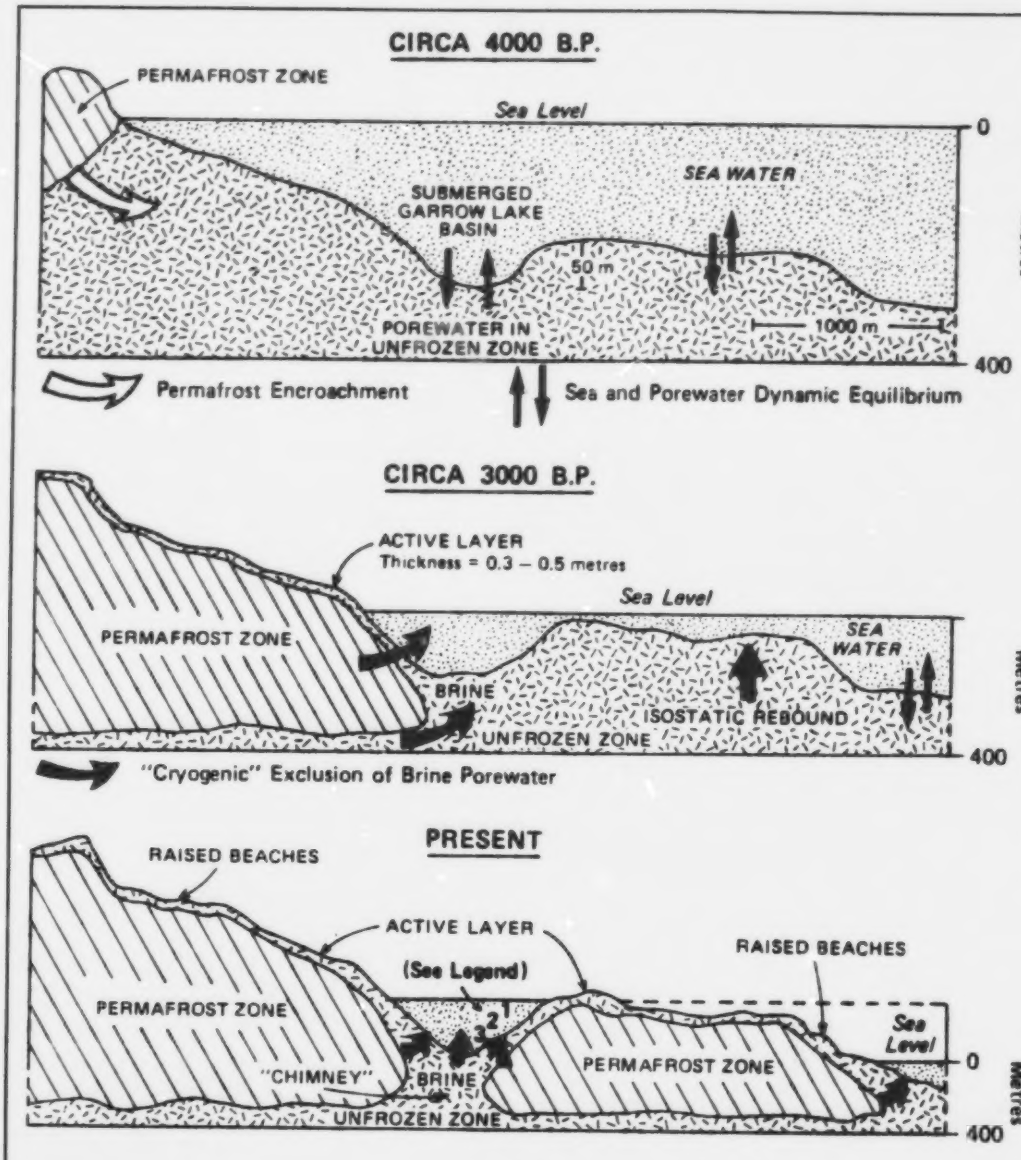
no permafrost exists beneath the centre of Garrow Lake, and none develops even if the surface temperature is greatly lowered.

Since the permafrost thickness at the mine may be anomalously low due to its close proximity to the coast, the same set of conditions were entered with half the geothermal gradient (Figure 6, lines C,D). Temperatures now reach their minimum value 150-300 m below the bottom of Garrow Lake, but these minima are still well above 0°C. Indeed, a mean surface temperature of about -29°C would be necessary before the theorized talik below Garrow Lake would no longer be throughgoing (Figure 6, line E). Because it is so unlikely that annual mean surface temperatures would reach this level, it is reasonable to argue on theoretical grounds that a throughgoing talik exists below Garrow Lake (Figure 7).

Active Layer Analyses

The soil surface salinity was surprisingly high near Garrow Lake, but decreased markedly with depth below the active layer (Table 1).

This vertical chloride distribution suggests that salt is introduced at the surface by precipitation or sea-salt aerosols. Precipitation of chlorinity in 1981 at Mould Bay, N.W.T., which is at a similar latitude and distance from the coast as this study site, ranged from 1.6 to 31.0 mg/ℓ. These values are one to two orders of magnitude smaller than the estimated pore-water salinity at this site. Therefore, considerable drying by evaporation, or influx or airborne salt is required to achieve the observed concentrations. The soil salinity


CIRCA 4000 B.P.
PERMAFROST ZONE
Sea Level
0
SEA WATER
SUBMERGED GARROW LAKE BASIN
50 m
Metres
POREWATER IN UNFROZEN ZONE
1000 m
400
Permafrost Encroachment
Sea and Porewater Dynamic Equilibrium
CIRCA 3000 B.P.
ACTIVE LAYER
Thickness = 0.3 – 0.5 metres
Sea Level
PERMAFROST ZONE
SEA WATER
Metres
BRINE
ISOSTATIC REBOUND
UNFROZEN ZONE
400
"Cryogenic" Exclusion of Brine Porewater
PRESENT
RAISED BEACHES
ACTIVE LAYER
(See Legend)
RAISED BEACHES
1
2
3
PERMAFROST ZONE
PERMAFROST ZONE
Sea Level
0
Metres
"CHIMNEY"
BRINE
UNFROZEN ZONE
400

LEGEND

1. MIXOLIMNION (0 – 19 m.) with a ^{14}C age which is not significantly different from present.
2. CHEMOCLINE (ie. Halocline and Pycnocline) at 20 m.
   ^{14}C age at 27 – 29m. = 3,850 ±200 years B.P. (From Pagé, 1988)
3. MONIMOLIMNION (21 – 45 m.)
   ^{14}C age at 45 – 47m. = 4,150 ±100 years B.P. (From Pagé, 1988)

FIGURE 7: Schematic representation of hypothetical changes in sea-level and permafrost boundaries at the Garrow Lake site during isostatic rebound. Permafrost boundaries are conceptual (not measured).

TABLE 1: VERTICAL CHLORIDE DISTRIBUTION NEAR GARROW LAKE.

SAMPLE SITE AND DEPTHS	CS[1] (mg/g)	CW[2] (mg/ℓ)
Core #1 - 30 m from shore		
0-5.5 cm	3.12	17,051
5.5-11 cm	0.23	1,273
11-15.5 cm	0.131	720
15.5-22 cm	0.047	259
Core #2 - 60 m from shore		
0-2 cm	1.29	6,906
2-10 cm	0.409	2,250
10-18 cm	0.281	1,554
18-24 cm	0.270	1,510
Core #3 - 90 m from shore		
0-2 cm	1.732	9,400
2-7.5 cm	0.484	2,664
7.5-13 cm	0.209	1,147
13-20 cm	0.337	1,843

[1] Mg of chloride/g of soil.
[2] Pore-water chlorinity.

is high relative to precipitation. The active-layer contribution to lake water salinity is therefore minimal due to the low precipitation in this portion of the High Arctic.

DISCUSSION

Ice, Wind and Thermoclines

Garrow Lake displays an unusual vertical temperature profile. In addition to its elevated mid-depth water temperatures, it exhibits multiple thermoclines. During most years, the lake is partially ice-covered during late August prior to its freeze-up in early September. In August 1982, however, the lake was entirely ice free for a 2-3 week period just prior to its freeze-up. Consequently, wind-generated currents mixed the epilimnion to a depth of 10 m (Figure 2) rather than to depths of 5-7 m as was the case in those years when a partial ice-cover persisted. Thus multiple thermoclines in Garrow Lake are probably the result of deep-mixing episodes during rare ice-free periods. This is an entirely different mechanism for multiple thermocline formation than has been previously described. Traditionally, multiple thermoclines have been ascribed to periods of deep wind-mixing followed by calm and solar-heating which are then followed by a subsequent period of shallow wind-mixing (Hutchinson 1957; Wetzel 1983). In Garrow Lake, the presence of a partial (or complete) ice-cover throughout the year restricts wind-generated currents to the top of the lake's mixolimnion (5-7 m). Only in those rare years when the lake is entirely ice-free for some, albeit brief, period, the ever present wind will cause the mixolimnion to mix to a depth of 10-12 m thus giving rise to multiple thermoclines in Garrow Lake.

The same mechanism that created the Garrow Lake multiple thermocline was probably also responsible for multiple halocline and multiple chemocline formation (Figures 3, 4). In August 1981, the water in Garrow Lake above a depth of 4 m had a salinity of 1-7 parts per thousand (PPT). Below this depth salinity increased rapidly to 60 PPT (approximately two times that of sea water). Below 20 m, salinity increased much more gradually until it reached nearly 2.5 times that of sea water (Figure 3).

During the ice-free period in August 1982, the salinity-profile changed to that represented by the dashed line (Figure 3). For purposes of clarity, the other years have not been superimposed on the depth-salinity profiles. However, the specific conductivity profiles (Figure 4), which mirror the salinity profiles, are provided for each of the five periods that the lake was studied between August 1980 and August 1987. The specific conductivity profiles indicate that once the lake was mixed to a depth of 10 m in August 1982, a brackish-water layer redeveloped at 0-3 m (Figure 4).

In summary, in the absence of late summer ice-cover, the wind mixes the Garrow Lake melt-water with the upper layer of saline water forming a 10 m deep brackish layer of low salinity (Figure 3). During those years when Garrow Lake is partially ice-covered throughout summer and fall, a shallow thermocline develops and the water immediately below the melting ice is nearly fresh.

Freezing-out Processes

During ice formation (freeze-up), dissolved salts and gases are forced out of the ice-crystal lattices and some of these salts and gases are injected into the water below the ice

(Goldman 1970). Once formed, this denser saline water containing high concentrations of dissolved gases begins to sink. This continues until the sinking water-mass reaches a depth of equal density (Goldman 1970).

Both salts and gases formed from "freezing-out" processes remain at this depth or pass into the more saline layer below the uppermost thermocline. Dissolved oxygen below the thermocline climbs to 140% supersaturation in the 5-10 m deep water-layer (Figure 5). Thus supersaturation results from freezing-out and not from photosynthesis, which was shown to be negligible at these depths (Dickman and Ouellet 1987). Oxygen, which accumulates below the thermocline during freezing-out events, is trapped there unless the lake mixes to a greater depth as occurred in August 1982.

The salinity, conductivity, and dissolved-oxygen profiles for Garrow Lake reflect four depth-zones: (1) a 0-5 m mixolimnion with low salinity resulting from ice melt-water. This zone is saturated with dissolved oxygen; (2) a 5-12 m brackish-water zone with supersaturated dissolved oxygen resulting from freezing-out processes; (3) a 12-20 m deep chemocline (chemolimnion) displaying a strong salinity gradient and rapidly decreasing dissolved oxygen; and (4) an anaerobic, deep (20-47 m) monimolimnion with hypersaline water (2.5 times the salinity of sea water, Figures 2-5). Oxygen in the bottom layer (20-47 m) was long ago completely depleted by the decomposition of organic matter which settled into the monimolimnion (Pagé *et al.* 1987). The 25 m deep anaerobic zone (Figure 5) was capped by a mass of phototrophic bacteria (Dickman and Ouellet 1983, 1987).

Since dissolved oxygen from freezing-out events is concentrated above the chemocline, probably this mechanism does not account for the observed hypersalinity of Garrow Lake. This is in contrast to Goldman *et al.* (1967) who reported that the high monimolimnetic salt-concentrations in Lake Vanda, located in the Wright Valley, Antarctica, were due largely to the freezing-out of salts from the lake's surface waters; a process that they referred to as "cryogenic meromixis".

Cryogenic Exclusion of Pore Waters

We believe that freezing-out of marine pore waters (cryogenic exclusion) from below Garrow Lake was most important in establishing the lake's high monimolimnetic salinity. The exclusion of salts would result in ice bodies or vugs of low salinity, such as those reported from the nearby Polaris Mine by Cominco geologists (Pagé *et al.* 1984). Isotopic analysis of the ice in these vugs indicated that their carbon and oxygen-isotope ratios (Pagé *et al.* 1987) were consistent with the isostatic rebound, freezing-out hypothesis.

Saline pore water trapped within the layers of rock below Garrow Lake would have resulted in salty brines being forced up into the bottom of the lake (Figure 7). According to this scenario, as the island uplifted and the sea receded, permafrost would have aggraded into the lake's watershed, freezing the pore water as it did so. The resulting brines from the freezing-out of salts within the sedimentary pore water would have been concentrated within the talik, and in Garrow Lake itself (Figure 7). Solute rejection during ground-freezing with salt concentration in adjacent pore water, has been reported from laboratory and field studies (e.g. Hallet 1978; Chamberlain 1983; Kay and Groenevelt 1983), so this appears to be a viable hypothesis. However, the extremely high salt-concentrations recorded for Garrow Lake are not known to have been produced in laboratory or field experiments. If the mechanism described is correct, other deep hypersaline meromictic lakes may well be found in the future below marine limit within the Arctic Archipelago.

CONCLUSIONS

1. Garrow Lake displays higher mid-water salinities and temperatures than any Arctic lake described in the published literature.
2. Calculations of the permafrost depth below the centre of Garrow Lake indicated that there is probably a throughgoing talik, or chimney, which would permit the entry of saline brines into the lake's monimolimnion following isostatic uplift, and solute rejection during the accompanying ground-freezing.
3. The active layer of sediment in the Garrow Lake Basin has unusually high salinities (0.05 - 3.1 mg/g) resulting from aerosol inputs and high evaporation and low precipitation levels.
4. Supersaturation of dissolved oxygen at 5-10 m in Garrow Lake was ascribed to freezing-out processes.
5. Multiple thermocline formation in Garrow Lake was ascribed to the incomplete mixing of its epilimnion (upper mixolimnion) during years in which ice-out did not occur or was incomplete.

6. Cryogenic exclusion of brine pore water was probably the chief mechanism responsible for the high monimolimnetic salinities in Garrow Lake.

REFERENCES

Anonymous. 1982. Canadian climate normals 1951-1980. Volume 2. Temperature. Environment Canada, Ottawa. 306 pp.

______. 1987. CANSAP data summary, atmospheric research. Environment Canada, Atmospheric Environment Service UDC 551.578.8, Ottawa.

Brown, R.J.E. 1972. Permafrost in the Canadian Arctic Archipelago. Zeitschrift für Geomorphologie Supplementband 13:102-130.

Chamberlain, E.J. 1983. Frost heave of saline soils. In: Proceedings, Fourth International Conference on Permafrost, Fairbanks, Alaska (July 17-22, 1983). National Academy of Sciences. Washington, D.C. pp. 121-126.

Cohen, Y., W.E. Krumbern, and M.Shibo. 1977. Solar Lake (Sinai), Part 3. Bacterial distribution and production. Limnology and Oceanography 22:621-634.

Dickman, M. and M. Ouellet. 1983. Limnological aspects of meromictic Lake Garrow. Université du Québec, INRS-Eau Internal Report No. 73:1732.

______. 1987. Limnology of Garrow Lake, N.W.T., Canada. Polar Record 23(146):531-549.

Drake, J. 1984. Polaris underground. Orbit 14:3-9.

Fallis, B.W. and S.M. Harbicht. 1980. A preliminary study of the limnology and biology of Garrow Lake, N.W.T. Western Region, Department of Fisheries and Oceans, Winnipeg, Technical Report. 89 pp.

Findlay, D.L. and H.J. Kling. 1979. A species list and pictorial references to the phytoplankton of central and northern Canada. Parts I and II. Fisheries and Marine Science Manuscript Report No. 1503:1-619.

Goldman, C.R. 1970. Antarctic freshwater ecosystems. In: Antarctic Ecology, Vol. 2. Edited by: M.W. Holdgate. Academic Press. London and New York. pp. 609-627.

Goldman, C.R., D.J. Mason, and J.E. Hobbie. 1967. Two antarctic desert lakes. Limnology and Oceanography 12:295-310.

Hallet, B. 1978. Solute redistribution in freezing ground. In: Proceedings of the Third International Conference on Permafrost, Edmonton Alberta. (July 10-13, 1978). National Research Council of Canada, Ottawa. pp. 85-91.

Harris, H.J.H. and K. Cartwright. 1981. Hydrology of the Don Juan Basin, Wright Valley, Antarctica. In: Dry Valley Drilling Project. Edited by: L.D. McGinnis. American Geophysical Union, Antarctic Research Series 33:161-184.

Harris, H.J.H., K. Cartwright, and T. Torii. 1979. Dynamic chemical equilibrium in a polar desert pond: a sensitive index of meteorological cycles. Science 204:301-303.

Hattersley-Smith, G. and H. Serson. 1964. Stratified water of a glacial lake in northern Ellesmere Island. Arctic 7:108-111.

Hattersley-Smith, G., J.E. Keys, H. Serson, and J.E. Mielke. 1970. Density stratified lakes in northern Ellesmere Island. Nature 225:55-56.

Heywood, R.B. 1987. Antarctic freshwater ecosystems: review and synthesis, adaptations within antarctic ecosystems. In: Proceedings of the Third SCAR Symposium on Antarctic Biology. Edited by: D.A. Llano. Smithsonian Institution, Antarctic Research Series 53:801-821.

Hutchinson, G.E. 1957. A treatise on limnology. I. Geography, physics and chemistry. John Wiley and Sons, Inc., New York. 1015 pp.

Kay, B.D. and P.H. Groenevelt. 1983. The redistribution of solutes in freezing soil: exclusion of solutes. In: Proceedings, Fourth International Conference on Permafrost, Fairbanks, Alaska (July 17-22, 1983). National Academy of Sciences. Washington, D.C. pp. 584-588.

Kovio, L.K. and J.C. Ritchie. 1978. Modern diatom assemblages from lake sediments in the boreal-arctic transition range near the Mackenzie Delta, N.W.T., Canada. Canadian Journal of Botany 56:1010-1020.

Lachenbruch, A.H. and B.V. Marshall. 1969. Heat flow in the Arctic. In: Proceedings of the U.S. Naval Arctic Research Laboratory Dedication Symposium, Fairbanks, Alaska. (April 9-12, 1969). Arctic 22:300-311.

Mackay, J.R. 1961. Pingos of the Pleistocene Mackenzie Delta area. Geographical Bulletin 5(2):21-63.

Ouellet, M., M. Bisson, P. Pagé, and M. Dickman. 1987. Physicochemical limnology of meromictic saline Lake Sophia, Canadian Arctic Archipelago. Arctic and Alpine Research 19:305-312.

Pagé, P., M. Ouellet, C. Hillaire-Marcel, and M. Dickman. 1984. Isotopic analysis of two meromictic lakes in the Canadian Arctic Archipelago. Limnology and Oceanography 29:564-573.

Pagé, P., J. Michaud, M. Ouellet, and M. Dickman. 1987. Isotopic composition and origin of lacustrine brines in the Arctic. Canadian Journal of Earth Sciences 24:210-216.

Stewart, K.M. and R.F. Platford. 1986. Hypersaline gradients in two Canadian Arctic lakes. Canadian Journal of Fisheries and Aquatic Science 43(9):1795-1803.

Thompson, T.G. and K.H. Nelson. 1956. Concentration of brines and deposition of salts from sea water under frigid conditions. American Journal of Science 254:227-238.

Torii, T. and N. Yamagata. 1981. Limnological studies of saline lakes in the dry valleys. In: Dry Valley Drilling Project. Edited by: L.D. McGinnis. American Geophysical Union. Antarctic Research Series 33. pp. 141-160.

Torii, T., N. Yamagata, J. Ossaka, and S. Murata. 1978. A view on the formation of saline waters in the dry valleys. In: Dry Valley Drilling Project (DVDP). Edited by: L.D. McGinnis, T. Nagara, R.B. Thomason, M.D. Turner. National Institute of Polar Research, Tokyo. Bulletin No. 8. Seminar III, pp. 96-97.

Trolle, A. 1913. Hydrographical observations from the Denmark Expedition. Denmark Kommissionen for Geologiske og Geografiske Undersogelser. Meddelelser om Grønland 41:271-426.

Wetzel, R.G. 1983. Limnology. Saunders College Publishing, Philadelphia. 767 pp.

Wilson, A.T. 1979A. A review of the geochemistry and lake physics of the Antarctic dry areas. In: Dry Valley Drilling Project. Edited by: L.D. McGinnis. American Geophysical Union. Antarctic Research Series 33. pp. 185-192.

______. 1979B. Geochemical problems of the Antarctic dry areas. Nature 280:205-208.

Wright, S.W. and H.R. Burton. 1981. The biology of Antarctic saline lakes - a review. Hydrobiologia 82:319-338.

Yamagata, N., T. Torii, and S. Murata. 1967. Report of the Japanese summer parties in Dry Valley, Victoria Land, 1963-1965. Report V. Chemical composition of lake waters. Antarctic Research (Japan) 29:2339-2361.

Yoshida, Y., T. Torii, and N. Yamagata. 1970. Antarctic saline lakes. In: Proceedings of Symposium on Hydrogeochemistry and Biogeochemistry, Vol. 1. Edited by: E. Ingerson. Clark. Washington, D.C. pp. 652-660.

ICE/WATER INTERACTIONS AND THEIR EFFECT ON BIOLOGICAL OCEANOGRAPHY IN THE ARCTIC ARCHIPELAGO

Robert J. Conover,[1] Glen F. Cota,[2] W. Glen Harrison,[1] Edward P.W. Horne,[1] and Ralph E.H. Smith[3]

Abstract: Although ice limits light penetration into Arctic seas, it also provides physical stability in early spring to permit primary production at approximately the same season as in lower latitudes. Epontic algae become associated with the ice in the fall and begin rapid growth in early April. The plants are shade-adapted and rapidly produce large populations on the underside of the still-forming ice. Nutrient levels in water which is constantly bathing the under-ice surface are high, but, because of very high concentrations of algae in an ice matrix, diffusion cannot supply all plant requirements. Highest rates of photosynthesis occur during spring tides when tidal currents are strongest. Epontic (under-ice surface) algae support many animals that live on or in the ice, and algal cells are constantly eroding into the water column to support continued development of some plankton animals and to initiate reproduction in others. Strong tidal currents also cause higher rates of algal erosion and better feeding conditions for planktonic animals. Light, currents and food conditions all influence the vertical distribution of plankton animals under the ice. Both diel and seasonal migrations are observed. Young stages of many benthic animals are initially associated with the ice as are young arctic cod. The "double benthos" in the Arctic Archipelago, one upside down, temporary and very productive, and the other still relatively near the surface and the recipient of unused production from above, together contribute to the region's richness in mammals and birds.

Résumé: Bien que la glace limite la pénétration de la lumière dans les mers arctiques, elle y apporte aussi une stabilité physique, au début du printemps, qui permet à la production primaire de se faire à peu près à la même saison que sous des latitudes plus basses. Les algues épontiques deviennent associées à la glace en automne et commencent à croître rapidement au début d'avril. Les plantes sont adaptées à l'ombre et produisent rapidement de vastes colonies sur le dessous de la glace encore en formation. Les niveaux de nutriments dans l'eau qui baigne constamment la surface inférieure de la glace sont élevés, mais, en raison des concentrations très élevées des algues, la diffusion ne peut pas subvenir à la totalité des besoins des plantes. Les taux les plus élevés de photosynthèse se manifestent pendant les marées de printemps où les courants de marée sont les plus forts. Les algues épontiques (sous la surface de la glace) alimentent bien des animaux qui vivent sur ou dans la glace, et des cellules d'algues se détachent continuellement dans la colonne d'eau, participant au développement régulier de certains éléments de plancton et démarrant la reproduction d'autres. Les forts courants de marée causent aussi beaucoup d'érosion des algues, donc de meilleures conditions d'alimentation du plancton. Les conditions de lumière, de courants et de nourriture ont tous une influence sur la distribution verticale des éléments de plancton sous la glace. On y observe des migrations nycthémérales et saisonnières. Les stades jeunes de bien des animaux benthiques sont initialement associés à la glace; c'est le cas de la jeune morue arctique. Le "double benthos" de l'archipel arctique, l'un à l'envers, temporaire et très productif, l'autre encore assez proche de la surface et récupérant la production inutilisée d'en haut, contribue à la richesse de la région en mammifères et en oiseaux.

INTRODUCTION

For those arctic inhabitants wandering over the polar landmass or those that are at least part of the year haul out on the ice, air temperature (which may fluctuate seasonally by perhaps 50 to 75°) introduces a large, though natural element of stress to their existence. In contrast, organisms spending all their life in arctic seas never know temperatures colder than a relatively balmy -1.8°C, and hardly become overheated at 2 or 3°C in mid-summer - especially as cooler waters are only a few metres below the shallow seasonal thermocline. Most of the poikilothermal (cold-blooded) organisms are also psychrophilic (cold-adapted), whether autotrophic (primary producers) or heterotrophic (energy consumers). So temperature itself is of small concern in their life.

---

[1] Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia B2Y 4A2
[2] Graduate Program in Ecology, University of Tennessee, Knoxville, Tennessee 37996-1610, U.S.A.
[3] Biology Department, University of Waterloo, Waterloo, Ontario N2L 3G1

One manifestation of low temperature, ice, is of great importance in the lives of northern aquatic organisms, however. It alters the physical environment of polar organisms in several unique ways. While forming and melting, it affects the structure and chemistry of the underlying sea water, removing fresh water and concentrating salt in the fall, and diluting the surface water in early summer. Convective mixing is associated with the sinking of the more dense, saltier water during freeze-up, but under ice, wind-driven mixing is of little significance. Lighter water of reduced salinity in spring tends to stabilize the water column and further reduce mixing. In the absence of wind effects, tidal forces become the dominant mixing mechanism in the relatively shallow straits and passages within the Arctic Archipelago. Turbulence normally associated with channelized flow of relatively high velocity is, however, reduced at a boundary layer such as the under-ice surface. But the rising and falling tide near shore, fractures the ice, contributing to the formation of pressure ridges and roughened under-ice topography, that in turn increases turbulence locally. As it thickens and develops a covering of snow, ice itself becomes an insulator against further heat-loss, and its rate of growth slows. At the same time, solar radiation is both reflected from the surface and absorbed by snow and ice in proportion to its thickness, which greatly influences rates of photosynthesis in the underlying water.

That the interface between polar ice and underlying sea water provides a substrate for the development of a distinctive flora and fauna has been recognized since the middle of the last century (Horner 1985A). The organisms associated with the under-ice surface are usually said to be "epontic", and although several other more specific terms have been suggested as an alternative (e.g. "sympagic" as used in Figure 1 taken from Carey 1985), epontic is widely applied and will usually be used here. The traditional under-ice food web is supported by microalgae, consisting predominately of pennate diatoms "attached" to the ice. Also associated with the ice are a variety of animals, notably macrofaunal amphipods, believed to be the principal grazers, and a complex of meio- and microfauna such as harpacticoid and cyclopoid copepods, nematodes, Protozoa and the larvae of a number of benthic invertebrates. However, note that some of the pathways on Figure 1 are uncertain of inferred from other data. Qualitative and quantitative data concerning the functioning of this community are relatively limited.

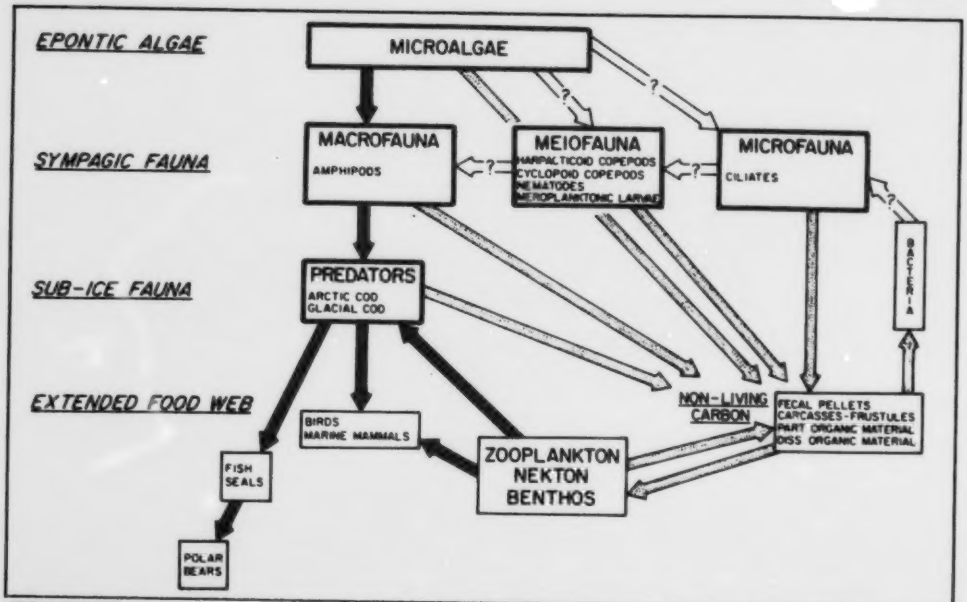

EPONTIC ALGAE
SYMPAGIC FAUNA
SUB-ICE FAUNA
EXTENDED FOOD WEB
MICROALGAE
MACROFAUNA
AMPHIPODS
MEIOFAUNA
HARPACTICOID COPEPODS
CYCLOPOID COPEPODS
NEMATODES
MEROPLANKTONIC LARVAE
MICROFAUNA
CILIATES
?
?
?
?
?
PREDATORS
ARCTIC COD
GLACIAL COD
BACTERIA
NON-LIVING CARBON
FECAL PELLETS
CARCASSES-FRUSTULES
PART ORGANIC MATERIAL
DISS ORGANIC MATERIAL
BIRDS
MARINE MAMMALS
ZOOPLANKTON
NEKTON
BENTHOS
FISH
SEALS
POLAR BEARS

FIGURE 1: A simplified food web to illustrate the major trophic relationships of the ice biota. The energetic linkages are designated at three levels of information: (1) solid arrows = observed; (2) stippled arrows = inferred from other data; and (3) open arrows = hypothesized (reprinted with permission from Carey (1985). Copyright CRC Press, Inc., Boca Raton).

For several years, we have been studying the epontic organisms in relation to their physical environment, and we present here some of our recent work illustrating the importance of under-ice biology in the functioning of arctic food-webs.

DESCRIPTION OF THE ENVIRONMENT

Barrow Strait is the shallowest part of the North-West Passage, there being no water deeper than 200 m between Cornwallis and Somerset islands (Figure 2). To the east the depth increases toward Lancaster Sound and Baffin Bay. Similarly, to the west there is increasing depth towards Viscount Melville Sound and Beaufort Sea. Indeed, shallow sills are characteristic of all the passages through the Arctic Islands so that only surface water can penetrate from the Arctic Ocean to the east. Water enters the Resolute area from the southwest by Somerset Island, from the west from Viscount Melville Sound and from the northwest around Cornwallis Island, and each water-type has slightly different characteristics which can also influence its zooplankton composition (Watson *et al.* 1988).

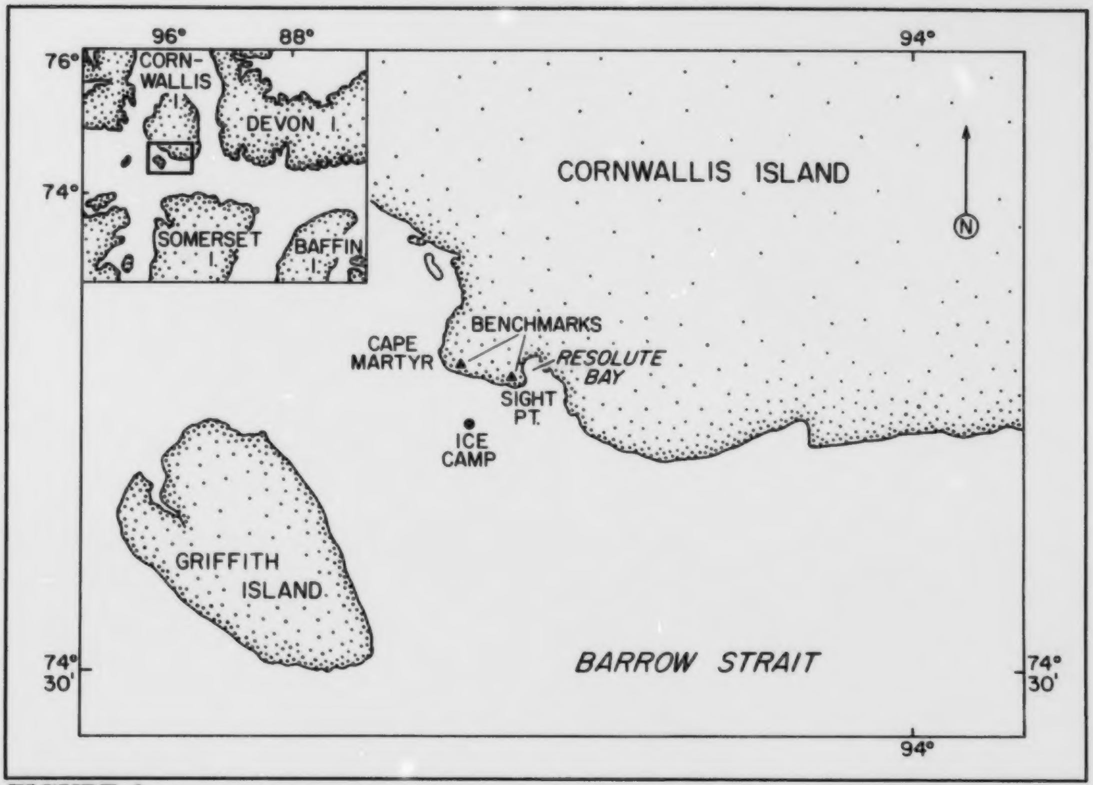

96°
88°
94°
76°
74°
CORN-WALLIS I.
DEVON I.
SOMERSET I.
BAFFIN I.
CORNWALLIS ISLAND
N
BENCHMARKS
CAPE MARTYR
RESOLUTE BAY
SIGHT PT.
ICE CAMP
GRIFFITH ISLAND
BARROW STRAIT
74° 30'
74° 30'
94°

FIGURE 2: **Ice camp off Resolute Bay and its location in the central Canadian Arctic Islands.**

The maximum tidal range in the Resolute Bay area is about 2 m, and tidal currents from the northwest in excess of 50 m s^{-1} have been observed locally in spring (Cota *et al.* 1987). For further information concerning the general physical oceanography of the region see Prinsenberg and Bennett (1987).

Barrow Strait is normally frozen from October to July, but in 1986 no permanent fast ice was established across to Somerset Island. That year was anomalously warm in December 1985 (5.9°C) and February 1986 (6.0°C) but normal or slightly below for the remaining months between October 1985 and May 1986 (Environment Canada 1986A).

Measurable light returns to the latitude of Resolute during the first week in February and disappears again the second week in November. Continuous light is recorded from the end of April to the middle of August (Environment Canada 1986B). Heaviest snowfall usually occurs in May (when it can seriously affect light-penetration through the ice at the season of maximum ice thickness), and again in early fall during a period of failing light but relatively thin ice.

SITE DESCRIPTION

The position of our station in 1987 (74° 38' 50.7"N, 95° 01' 27.8"W; Figure 2) happened to correspond almost exactly with that of Station 31 (74° 38.4' N, 95° 01.1'W) of Prinsenberg and Bennett (1987). A site within 1-3 km of this location (Figure 2) has been occupied or used for sampling from mid-March to early July beginning in 1984, but not always over the same periods. At these stations water depth varied from 87 to 105 m. Ice and snow depth varied from year to year but were in the range of 1.5 to 2.1 and 0.1 to 0.5 m respectively, with snow depth being greatly influenced by local drifting.

METHODS

At the station, from one to three insulated, portable structures were set up (Parcoll, Panabec Manufacturing, Montreal) over a hole at least 0.75 m in diameter, previously cut in the ice to provide shelter, accommodation and laboratory space, as well as access to the water. Each shelter was supplied with at least one electrically-powered winch and such additional portable scientific equipment as required. Each Parcoll was served by a 5-7 kw diesel generator and a portable oil stove. Water samples were collected with Niskin bottles of appropriate size, or with an under-ice pumping system. In addition to plant pigments, we collected ice and water samples for analysis of ammonia, nitrate, silicate and phosphate by standard analytical methods. Particulate samples were collected from ice and water for determination of carbon, nitrogen, protein, soluble and structural carbohydrate, lipid and ATP. Zooplankton were captured with several sizes of relatively conventional nets lowered and then towed vertically over a measured distance before being closed with a throttling system, or mounted so as to fish horizontally at a given depth in the tidal stream. Net diameters ranged from 0.5 to 1.0 m in diameter and were fitted with appropriate mesh between 30 and 1,800 μm, according to the size of organisms to be sampled. Zooplankton samples were preserved in 2% neutral formalin solution or frozen after filtration to remove excess sea water. Dry weight of zooplankton was determined routinely after drying at 60°C, and frozen samples were analyzed for gut-pigment following Mackas and Bohrer (1976). Some samples were analyzed for their proximate chemical composition as in the case of the other particulate samples mentioned above.

Generally, sampling the epontic algal community was carried out with a SIPRE coring auger. When larger quantities of ice algae were required, a JIFFY ice auger (23 or 25 cm diameter) was used to core to within a few centimetres of the algal layer and the remaining ice was broken free with an ice-chisel. The algal-rich ice chips could then be collected at the surface of the auger-hole with a household strainer. Sampling was often carried out through such auger-holes with a portable winch or pump when it was important to obtain information where the under-ice distribution of light was not affected by opaque objects introduced by humans.

In most cases physiological experiments with both plants and animals were carried out in incubators in the Parcoll cooled by continuously-flowing sea water pumped from beneath the ice. For most photosynthesis, nutrient-uptake and respiration studies, algae - containing ice from SIPRE cores was melted in sea water (~10:1 sea water:ice melt volume) and incubated over a range of light intensities simulating natural conditions under the ice. Carbon-14 and nitrogen-15 were used as tracers in most photosynthesis and nutrient-uptake investigations.

Current velocities and direction were routinely determined with an Aanderaa current meter, either as part of an array mounted under the ice and anchored to the bottom or mounted separately to an aluminum pole frozen in the ice. Density-profiles were taken with a Guildline Model 8770 portable CTD. Velocity-profiles in the top 30 cm of water directly under the ice were studied with a unique profiling system developed at BIO and Dalhousie University by Dr. Terry Chriss.

For details of the methods used in our studies, see references in the next section.

OBSERVATIONS

Epontic Algae

Apparently ice algae become associated with sea ice as soon as it is formed in the fall, but the mechanism is uncertain (Horner 1985B). What we do know is that sometime about the beginning of April the bottom of the ice shows enough colour to be detectable with the unaided eye. From that time until late May, the chlorophyll concentration at the interface increases in roughly linear fashion and can exceed 200 mg Chl m-^{2}. Experimental manipulation of the snow cover has shown that optimal light conditions (those supporting maximum chlorophyll concentrations) for the algae are found within the range of naturally-occurring snow depth. Pigment concentrations under artificially snow-free ice are substantially below the maximum and maintaining such an area clear of snow for nearly two months does not augment the pigment crop, suggesting that the ice algae are genetically shade-adapted (Cota 1985).

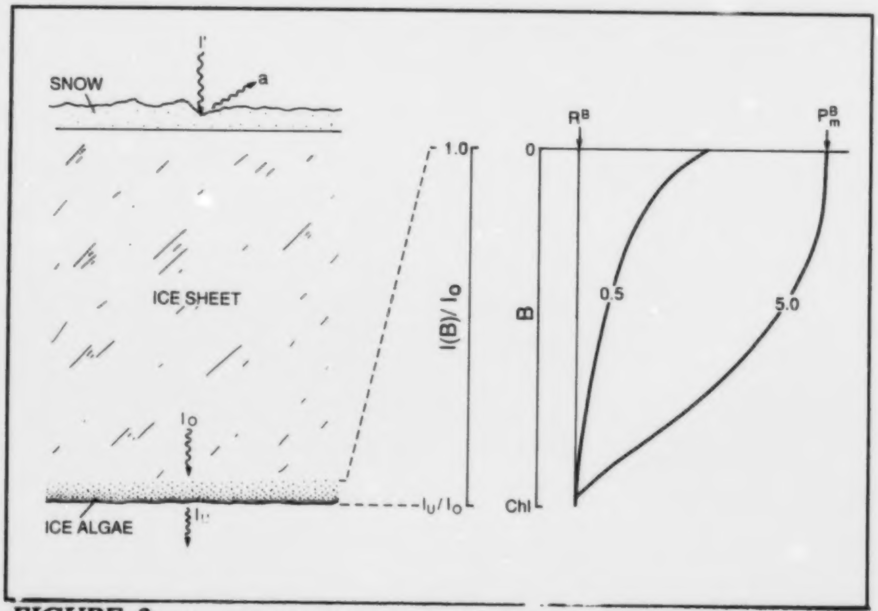


FIGURE 3: A cross-section of the annual sea-ice sheet, showing the relatively narrow zone of algal growth near the ice water interface (stippled area) and the downwelling solar radiation at the snow surface, the top of the algal layer, and at the ice water interface (I', I^o and I_μ respectively). Profiles of biomass-specific photosynthesis (thicker curves) and respiration (vertical line designated R^B) are shown as functions of areal chlorophyll concentration, B, and the correspondingly attenuated solar radiation, I(B), through the algal layer. The photosynthesis profiles illustrate two different ratios (0.5 and 5.0) if I_o to the photosynthetic parameter I^k. The remaining terms are defined and explained in the METHODS section.

How is the standing crop of ice algae controlled? Smith *et al.* (in press) constructed a model of how the physical environment affects the primary production of the epontic plants. The photon-flux density (PFD) in $\mu E\ m^{-2} s^{-1}$ (I' Figure 3), striking the snow surface of the frozen ocean will be partially reflected (a). The remainder will be subjected to three separate attenuation coefficients: k_s (cm^{-1}), operating on snow depth, Z_s (cm); k_i ($cm^{-1}1$) operating on ice thickness, Z_i (cm); and k_{chl} (m^2mg^{-1}), the attenuation coefficient for the ice algae themselves. These coefficients determine in additive fashion the amount of light reaching the sub-ice water, I_μ:

$$[1] \quad 1n(I_\mu/I') = -a\cdot -k_i\cdot Z_i - k_s \cdot Z_s - k_{chl}\cdot Chl.$$

The amount reaching the top of the algal layer is:

[2] $I_o = I' \cdot \exp(-a - k_i \cdot Z_i - k_s \cdot Z_s)$

At any level within the algal layer, the PFD reaching the cells is determined as:

[3] $I(B) = I_o \cdot \exp(-k_{chl} \cdot B)$, where B, the concentration of chlorophyll in mg m^{-2} varies from 0 at the top to Chl at the bottom (Figure 3).

Biomass-specific photosynthetic rate (P^B,$\mu gC \cdot \mu gChl\ a^{-1} \cdot h^{-1}$) as a function of PFD is often written (e.g. Lewis *et al.* 1985) as:

[4] $P^B = P^Bm \cdot [1 - \exp(I/I_k)]$,

where P^Bm is the light-saturated maximum in P^B and I_k is the "adaptation parameter", equivalent to P^Bm/α, where α is the initial slope of the P^B vs I curve. The algal respiration rate R^B in $\mu gC \cdot \mu gChl\ a^{-1} \cdot h^{-1}$ is assumed to be independent of light and a constant function of photosynthesis (Figure 3).

Also shown in Figure 3 are two theoretical curves relating photosynthetic rate at different depths in the algal layer to the ratio of the input level of illumination (I_o) and the adaptation parameter (I_k). Both curves are shown to attenuate to the point at which $R^B = P^B$, the compensation light level I_c. Here the chlorophyll concentration is at the light-limited maximum (B_{max}), and net production (P_{net}) is also maximized (Figure 4). The maximum possible integrated net production (P_{opt}) is the integrated difference between photosynthesis and respiration when Chl = B_{max}. Based on the foregoing relationships, B_{max} can be calculated as:

[5] $B_{max} = (-1/k_{chl} \cdot 1n[(-I_k/I_o)\ 1 \cdot 1n(1 - R^B/P^Bm)]$.

Smith *et al.* (in press A) have used these relationships to examine their own and others' data from both the Arctic and Antarctic. The average compensation intensity (I_c) was 0.56 $\mu E \cdot m^{-2} \cdot s^{-1}$ for the Resolute data, which might also be equivalent to I_{crit}, the intensity of light necessary to initiate ice algal growth in early spring, in which case epontic production could begin as early as the first week in March in a low-snow year (Smith *et al.*, in press

B). B_{max} values calculated for the Resolute area and from data in the literature for other arctic sites, virtually always equalled or exceeded the maximum standing crops measured in the field, and were only approached under conditions of very heavy snow and low standing crop. Hence, the model seems to provide a true upper bound, as imposed strictly by light limitation.

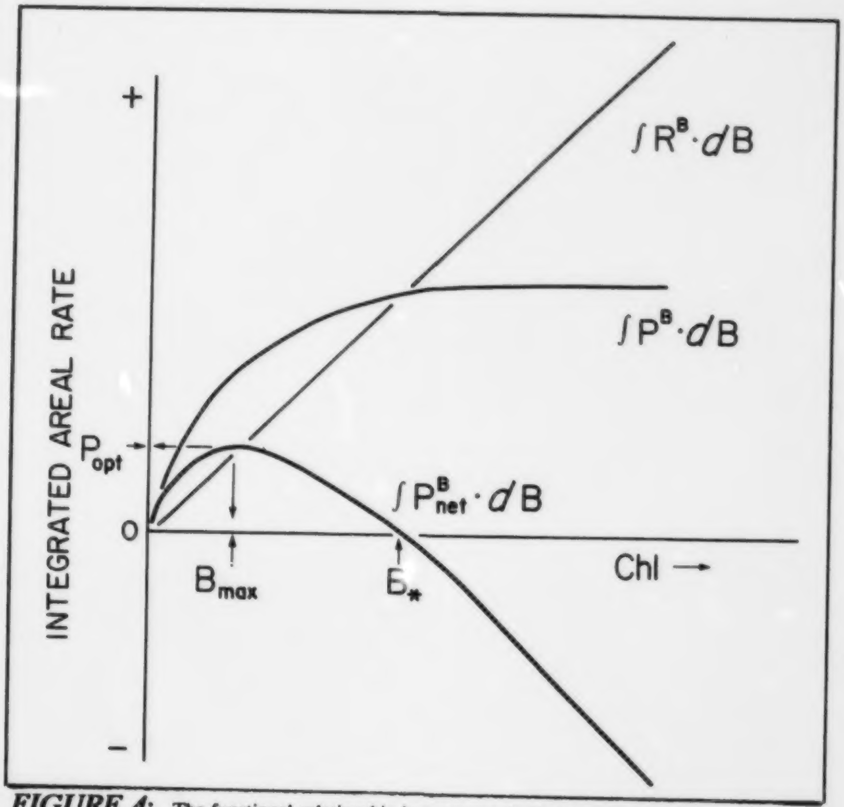


FIGURE 4: The functional relationship between vertically-integrated areal production and respiration rates ($mgC \cdot m^{-2} \cdot h^{-1}$) and integrated areal chlorophyll concentration, Chl ($mg \cdot m^{-2}$). All terms are described in the METHODS section.

While these observations are in complete agreement with the concept of light limitation as a controlling factor for ice-algal production, the fact that light parameters alone do not provide an accurate prediction of standing crops and growth rates suggests that there are others. The biomass of epontic algae, however determined, shows frequent oscillations over the spring-growth period. A probable association of such fluctuations with lunar tidal patterns has been observed several times (Figure 5a). Note also that in the Resolute area growth rate, nutrient demand and certain photosynthetic parameters also show a coupling with tidal range (Figure 5b,c). Greater allocation of recent products of photosynthesis to nitrogen-containing protein, rather than lipids and carbohydrates, was also correlated with greater tidal mixing (Smith *et al.* 1987).

Near the mouth of the Great Whale River, in Hudson Bay, strong salinity-induced stability may inhibit the vertical advection of nutrients, especially phosphate, during periods

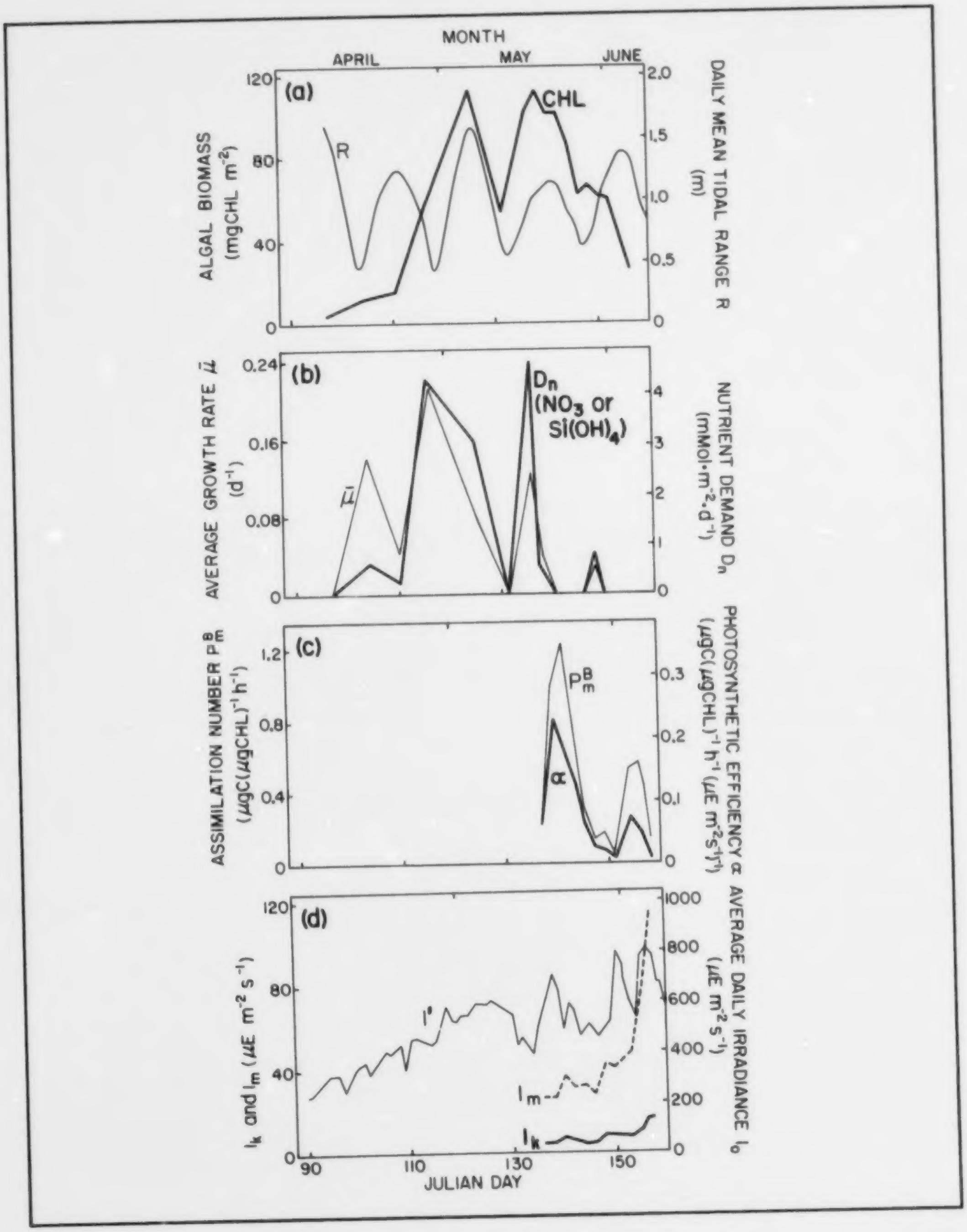


FIGURE 5: (a) The temporal development of the ice-algal bloom is shown as concentration of chlorophyll (CHL) plotted with the daily mean tidal range (R). The algae begin to slough off the ice toward the end of May. (b) Average growth rate (μ) is plotted with the estimated nutrient demand (D_n). (c) Photosynthetic performance if described by the maximum assimilation number $P^B m$) and the photosynthetic efficiency (a) is also shown for the latter part of the bloom. (d) The index of photoadaptation (I_k) and the optimal irradiance for photosynthesis (I_m) are plotted with the average daily incident irradiance (I) (from Cota and Home 1988).

of low tidal activity. During spring tides, greater mixing and entrainment of deeper water increases the available nutrients near the ice (Gosselin *et al.* 1985).

The explanation is not so obvious near Barrow Strait where tidal currents are generally strong and nutrient profiles suggest that there should be no limitation (Figure 6). There would certainly be sufficient nitrate, phosphate and silicate to support a phytoplankton bloom if the cells were more or less uniformly suspended over a length of water column and continuously bathed in the nutrient-rich water ... provided, of course, there was sufficient light. However, the ice algae are highly concentrated and growing in a layer as on an agar plate. Hence, the availability of nutrients is not the same to the cells deeper in the ice, but nearer to the light source, and to those at the bottom of the layer. So, in addition to a light gradient (Figure 3), there is also a nutrient gradient (Figure 7).

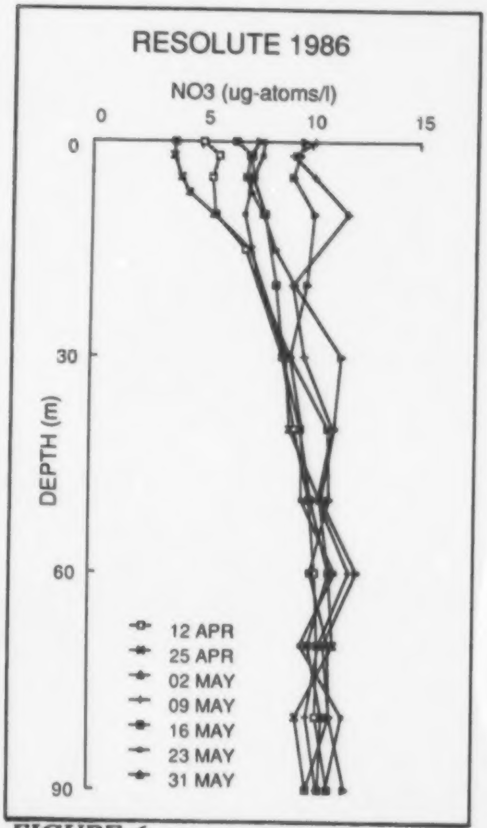


FIGURE 6: Profiles under the ice showing the vertical distribution of nitrate (NO_3) in μg-atoms l^{-1} on different dates in 1986.

Cota *et al.* (1987) have examined several mechanisms that might affect the nutrient demand along this gradient. The desalination process as ice forms results in drainage of brine through channels to the water beneath - even from the skeletal layer that supports algal growth. Some convective mixing is generated by this process, but it will be more important earlier in the season when the ice is growing rapidly. By May when the algal demands are highest, ice growth stops and hence brine-induced mixing would be minimal. Nutrient concentration parallels salinity concentration over most of the ice sheet so older ice is the most impoverished (Grainger 1977). Even if the nutrients in the entire ice sheet were available they would only support one or two weeks of rapid growth.

Regeneration within the algal layer is also potentially a mechanism wherein ammonia or other forms of organic nitrogen might become available for reuse. Using data on excretion by a variety of zooplankton, ciliates and bacteria from the literature, Cota *et al.*

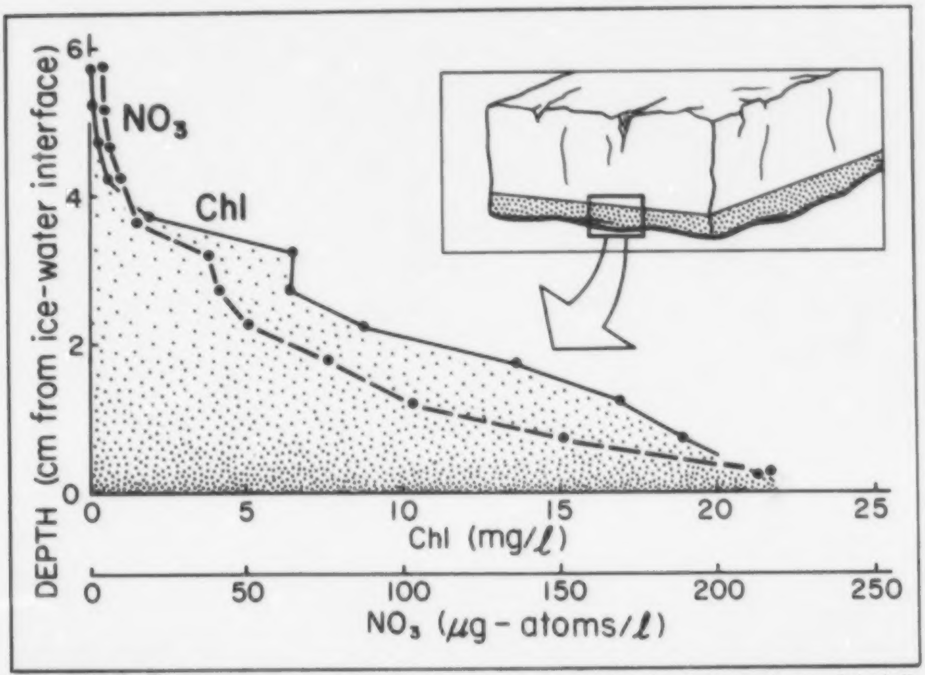


FIGURE 7: A cross-section of the annual sea-ice sheet, showing the algal-growth zone (stippled) enlarged to demonstrate the parallel distribution of nitrate (NO_3) and chlorophyll (Chl) in the bottom few centimeters of ice.

(1987) have calculated that the regenerative fluxes of ammonium-nitrogen might just meet the demand in some sub-ice environments, but the regeneration rate for silicic acid to make new diatom shells seems too low (Nelson and Gordon 1982).

So the primary source of nutrient enrichment must come from water near the epontic environment. Regardless of whether the concentrations near the ice are high or low, the important consideration is the rate of flux (i.e. renewal) across the mixed layer from the source of so-called "new" nutrients beneath the pycnocline. In their treatment, Cota *et al.* (1987) have set up a two-layer model with one gradient across the pycnocline and the second bringing material across the mixed layer to the ice. As the tidal range increases, the turbulent kinetic energy and the current shear both increase as the square of the daily range. The coefficient of vertical eddy diffusivity also varied by about an order of magnitude between the low neap tidal range and high springs. Although the fitted model does not match the data perfectly, a fortnightly pattern in the flux of both nitrate and silicic acid is demonstrable: the nutrient demands by the ice algae are easily satisfied during springs but are sometimes insufficient during neaps.

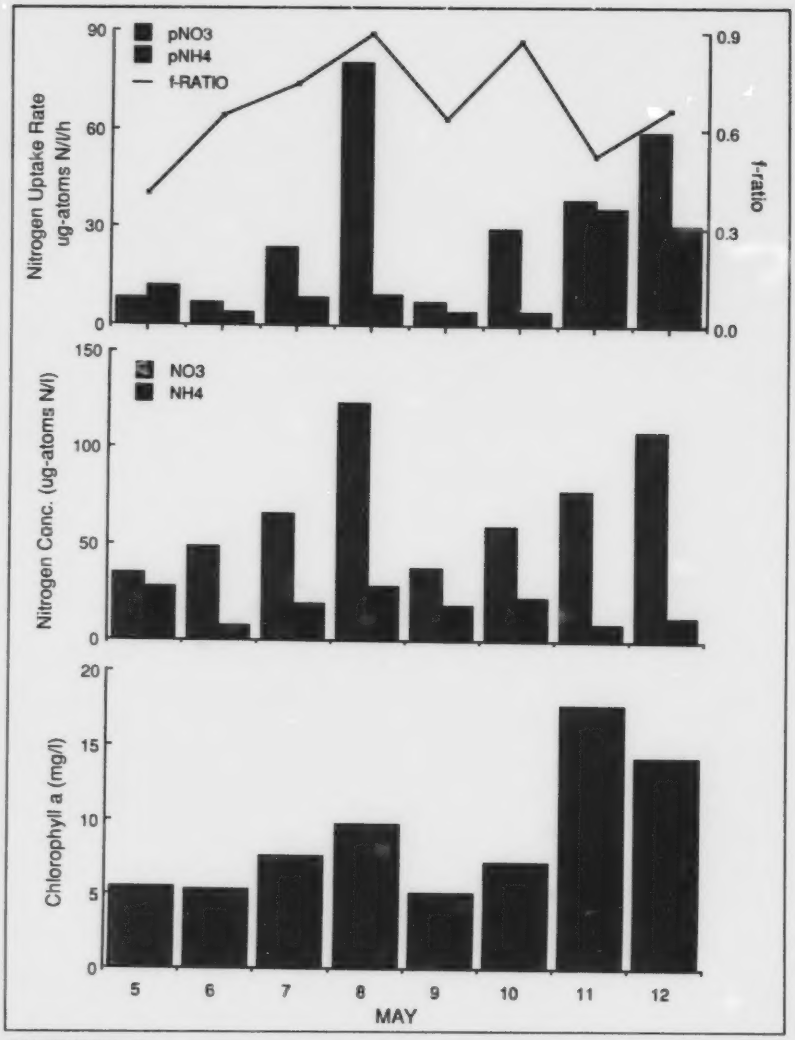


FIGURE 8: (Top) Bars give uptake rates for nitrate (pNO_3) and ammonium (pNH_4) in μg-atoms N $l^{-1}h^{-1}$ in the ice-algal layer; line shows the f-ratio, the fractionof the total nitrogen uptake supplied by nitrate. (Middle) Nitrate (NO_3) and ammonium (NH_4) concentrations in μg-atoms N l^{-1} in the ice-algal layer. (Bottom) Chlorophyll a concentration of mg l^{-1} in the ice-algal layer. All data from May 1986.

While we recognize the existence of a gradient across the algal growth layer (Figure 7), we have not yet measured the flux along it. Nonetheless, the concentrations of nitrate in the ice, though varying, are generally quite high - high enough to saturate the uptake system. Further, they can be an order of magnitude higher than in the adjacent sea water. At present, we do not know if the high concentrations, which also extend to ammonia, are in the interstitial water, and part of the ice/water complex, or perhaps are in the internal storage pools of the ice algae themselves. As shown in Figure 8, the amount and proportion of nitrate taken up (upper graph), the total amount of nitrate present (middle graph) and chlorophyll concentration in the ice (lower graph) are well correlated, which might indicate a direct association with living cells for all.

In conclusion, there seems to be a close coupling between the amount of tidal mixing and the production of epontic algae, but a precise understanding of how such physical forcing brings about the observed effects is still unclear. The case for nitrate as the limiting nutrient is weaker than before; perhaps silicic acid (G.F. Cota, unpublished data), or some still-unmeasured micronutrient is the key.

Sub-Ice Fauna

To address the importance of under-ice primary production in the ecology of high-latitude environments, we need to understand what happens to it and how it enters into the trophic structure. There have been several accounts of the composition of the fauna associated with the epontic algae (reviewed by Carey 1985), but relatively few attempts to determine the quantity of organisms, their biomass, or to quantify their food relations. Certainly the act of sampling this diverse assemblage is formidable. For the macrofauna, the usual approach is to manually scrape the under-ice surface with a diver-operated net designed to uniformly sample a linear transect, but photographic or visual analyses must be made to evaluate escapement which is greater if the ice surface is rough (Cross 1982; Gulliksen 1984). Visual methods have verified that macrofaunal amphipods are several times more abundant on rough than on smooth ice, with greatest abundance on multiyear ice (Gulliksen and Lønne 1987). Numbers were enormously variable, depending to some degree on ice-type, and, in terms of wet-weight, ranging from zero to more than 30 g m^{-2}.

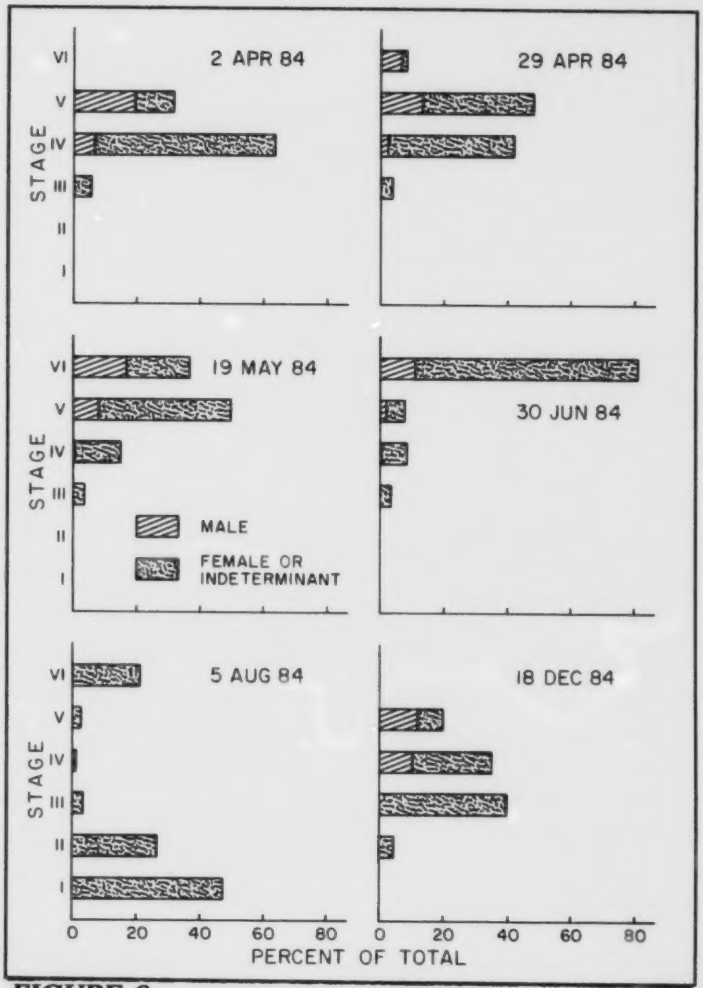


FIGURE 9: Population structure, on six dates in 1984, of the copepod, Pseudocalanus sp., shown as the percentage of the total of this species present in the water column in Resolute Passage that is contributed by each copepodid developmental stage.

Despite the overwhelming dominance of amphipods in macrofaunal collections, studies of the trophic relations at the ice edge off Pond Inlet suggested that the dominant nektonic predator, the Arctic cod, generally ate more calanoid copepods than other prey regardless of year-class or site of capture (Bradstreet and Cross 1982). So it became another objective of our research group to establish the association, if any, between the epontic algae and the planktonic animals living in the water beneath the ice.

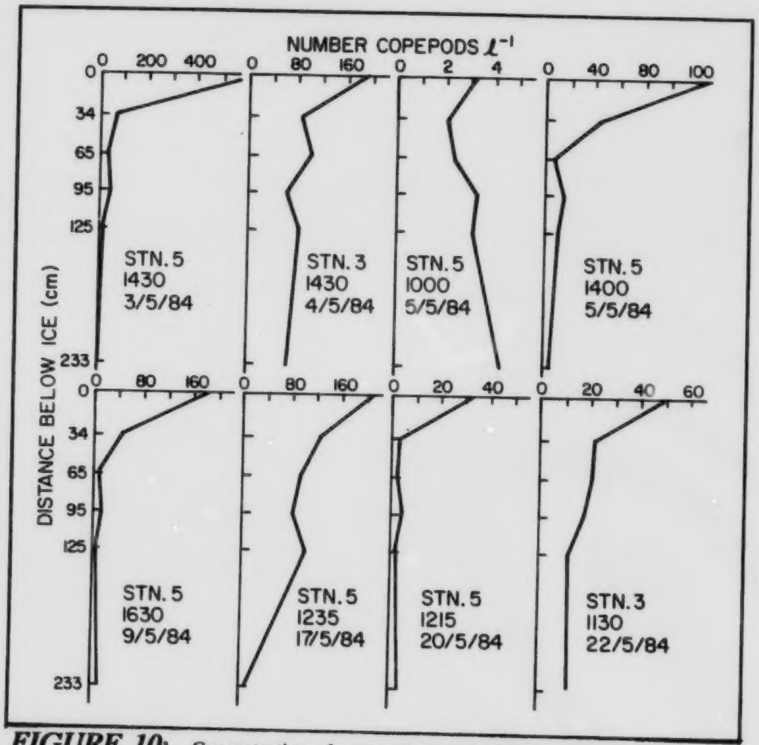


FIGURE 10: Concentration of copepods, largely Pseudocalanus sp., under the ice in the upper 2.3 m of the water column of Resolute Passage on seven dates in May 1984.

In 1984 we made a series of plankton tows, and took pump-samples during the fast-ice season, with additional tows in August and December, that showed the numerically-dominant copepod off Resolute (*Pseudocalanus* sp.) was growing and developing under the ice (Figure 9). There were virtually no sexually-mature individuals in the April 2 population, which was similar in structure to the overwintering population found the following December, but, in between, a generation matured by the end of June - well before the post-break-up bloom and its offspring developed over the "Arctic summer". We also found, using the pumping system, that at times *Pseudocalanus* as highly concentrated directly under the ice (Figure 10). Parallel feeding experiments, using algae melted from the ice, yielded rates comparable to the highest ever observed for the genus, even though our experimental temperature was 10-15°C colder than those used elsewhere (Conover *et al.* 1986). Animals could completely fill their guts 5-10 minutes after first exposure to food.

We were unable to see any clear pattern of vertical migration in 1984, but thought that there might be a relationship between "swarming" of *Pseudocalanus* near the ice and current speed. We hypothesized that the copepods, being hungry after a long winter, would seek the under-ice surface at every opportunity and should aggregate most efficiently near the ice during periods of minimal current. On the other hand, the strongest currents would erode the maximum amount of ice algae. Hence feeding and aggregation should be concentrated near the ice somewhat before slack water during declining flows. In the absence of direct current measurement in 1984, a tidal model was constructed that seemed to fit the hypothesis reasonably well on the basis of available data (Conover *et al.* 1986).

Attempts to verify the model in subsequent years suggested that the original hypothesis was too simple (Conover *et al.*, in press). For one thing, dense concentrations of *Pseudocalanus* were rare and very transitory. Then in 1986 attempts to establish a relationship between zooplankton behaviour and current speed were complicated by a diel migratory signal. Six 32-hour sampling regimes were established, three during neap and three during spring tides, and each was accompanied by detailed current observations. In all six experiments *Pseudocalanus* appeared in greater concentrations in the upper 10 m sometime between 1900 and 2400, although the timing varied somewhat on the different dates (Figure 11). Some individuals accumulated in the upper 1 m (dashed line, Figure 11), which was generally devoid of animals at other times. At 10 to 30 m depth there was no consistent pattern (dotted line, Figure 11).

Chlorophyll concentrations under the ice did not show an interpretable pattern relative to current velocity (Figure 11), which was generally the case for all six experiments. In contrast, gut-pigment concentrations in the animals, particularly those captured in the upper 10 m, showed an evening increase that correlated well (but sometimes with a time-lag) with the peak in abundance of animals in the upper waters. Moreover, the animals in the 10-30 m layer also showed a gut-pigment peak, which in four out of six experiments roughly coincided with that in the upper water, even though there was little evidence for a comparable migration. Mention has been made already of the open water in Barrow Strait in 1986, and the higher than usual concentrations of phytoplankton before break-up, so perhaps gut-pigment levels in the zooplankton were not related to ice-algal production then.

Other zooplanktonic forms accumulated in the vicinity of the ice/water interface, although their migratory behaviour was not usually predictable. The buoyant eggs of *Calanus hyperboreus* (the dominant herbivorous copepod of the High Arctic) develop under the ice so that its nauplii are in a favoured position for further development long before the ice goes out (Figure 12). Gut-pigment analysis has confirmed that they are feeding at times,

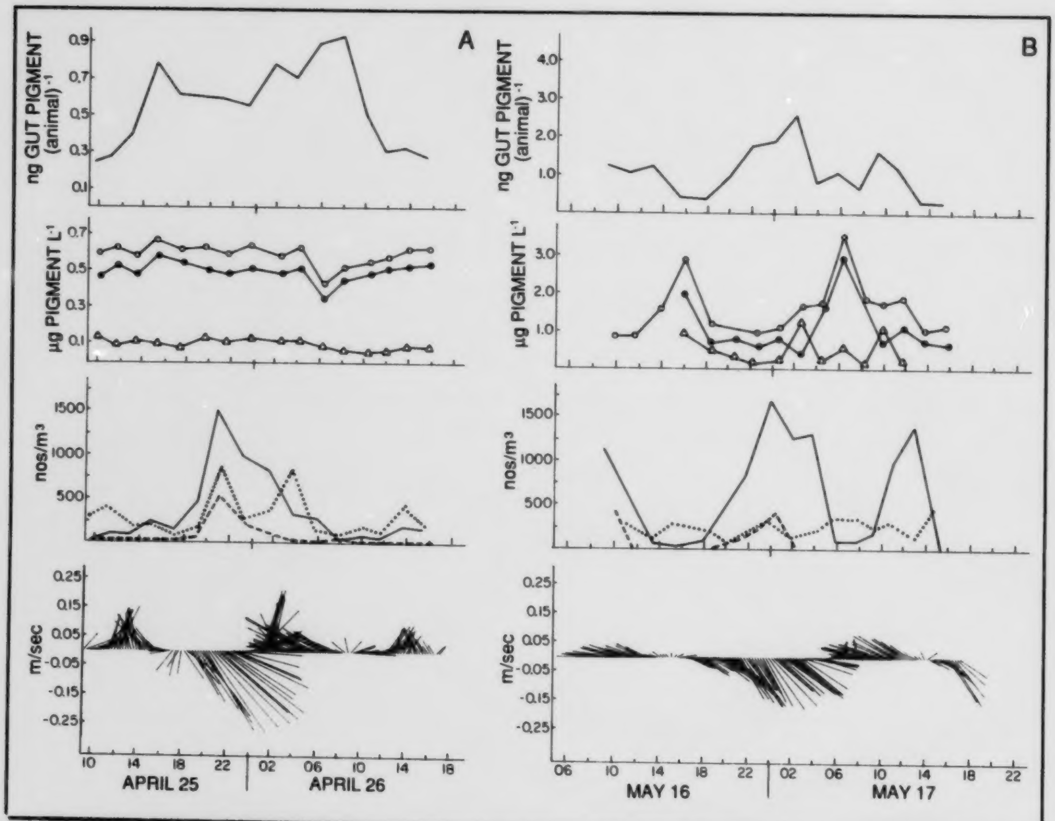


FIGURE 11: Representative diel observations for a spring (A, April 25-26, 1986) and a neap tide experiment (B, May 16-17, 1986). Bottom graph shows speed, in meters s^{-1}, and direction of tidal current with reference to the Y-axis, south being negative and north, positive. Second graph from the bottom gives numbers of *Pseudocalanus* sp. m^{-3} in three depth strata: (solid line) 0-10 m below ice; (dotted line) 10-30 m below ice; and (dashed line) 1 m below ice. Second graph from the top gives distribution of chlorophyll-derived pigments in $\mu g\ l^{-1}$ at 1 m below ice: (solid circles) chlorophyll a; (open triangles) pheopigments; and (open circles) total pigment. Top graph gives gut pigment in ng $(animal)^{-1}$.

but their abundance is so variable that we have been unable to see a pattern. Small copepods such as *Acartia longiremis* and *Oithona similis* occur regularly just under the ice, and, by late May, barnacle (cirripede) nauplii, the most abundant of a number of benthic invertebrate larvae, can completely dominate the samples (Figure 12).

Another large copepod, *Calanus glacialis*, seems to employ a somewhat different life-history strategy that is probably related to ice algae. In some parts of its range this species seems to require the presence of a phytoplankton bloom to induce maturation and spawning, for example, along the ice-edge in Fram Strait (Hirche and Bohrer 1987). In Resolute Passage the animals appear in the upper 30 m in mid-May and quickly mature. Because of their large size and relative scarcity, they are rarely caught with the pump so we do not know much about their movements near the ice, but they frequently contain chlorophyll-related pigment. In the laboratory they spawn readily, regardless of whether they receive food, but they laid more eggs when fed. So at least some of their offspring would get a head start, perhaps saving a year in the completion of their life-cycle.

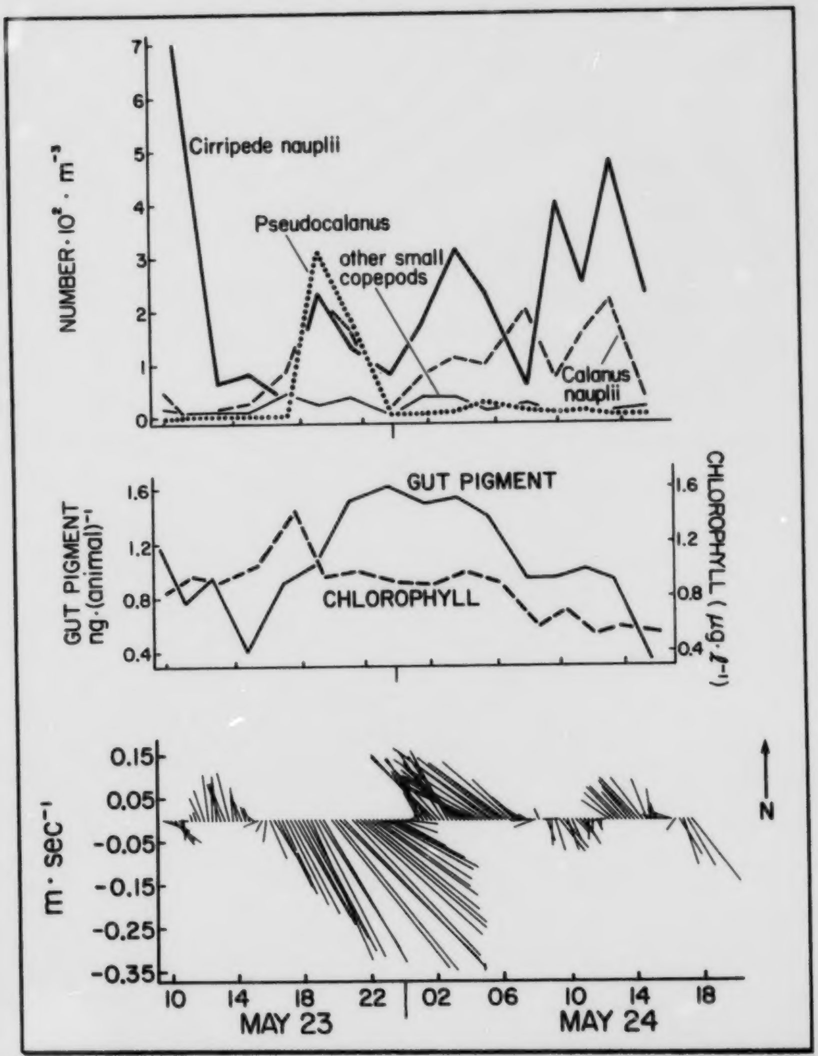


FIGURE 12: Diel observations for a spring tide experiment (May 23-24, 1986). Bottom graph shows current speed and direction (as in Figure 11). Middle graph gives gut pigment in animals (solid line) from the 10-30 m strata below ice in ng $(\text{animal})^{-1}$ and chlorophyll a in $\mu g\ l^{-1}$ (dashed line) at 1 m below ice. Top graph shows the number $\cdot 10^2 \cdot m^{-3}$ of Pseudocalanus (dotted line), Calanus hyperboreus nauplii (dashed line), other small copepods, predominantly Oithona and Acartia (thinner solid line), and cirripede nauplii (thicker solid line), all at 1 m below ice.

Boundary-Layer Physics

In a strong current, the liquid is turbulent and mixes rapidly, but near a surface (e.g. the under-ice surface) friction reduces mean velocity (Figure 13). As the turbulence is reduced, the water begins to act like an increasingly viscous fluid until the velocity is zero. The laws of physics argue that this process is a function of molecular viscosity, the density of the water and a stress term, from which one can calculate the thickness of the viscous boundary layer (linear velocity region).

In a controlled laboratory experiment it is easy to measure the controlling parameters and constants and predict the thickness of the viscous layer, but the natural environment can offer surprises. Using a system to actually measure the thickness of the viscous boundary layer on the underside of the ice, developed by Dr. Terry Chriss and BIO scientists, we found that the layer was substantially thicker than a laboratory experiment predicted. So deviation from linearity (Figure 13) should have been around 0.2 cm rather than a bit less than 0.4 as measured. In other words, the stress was somehow reduced because the molecular viscosity and density of the water were constant.

We believe the algae themselves are reducing the turbulence of the environment by making the water "slipperier", probably by secreting large molecules into their surroundings. In so doing they presumably favour their own survival in increased current velocity, and perhaps in a stronger nutrient flux, without exposing themselves to increased turbulence that could erode them from the ice.

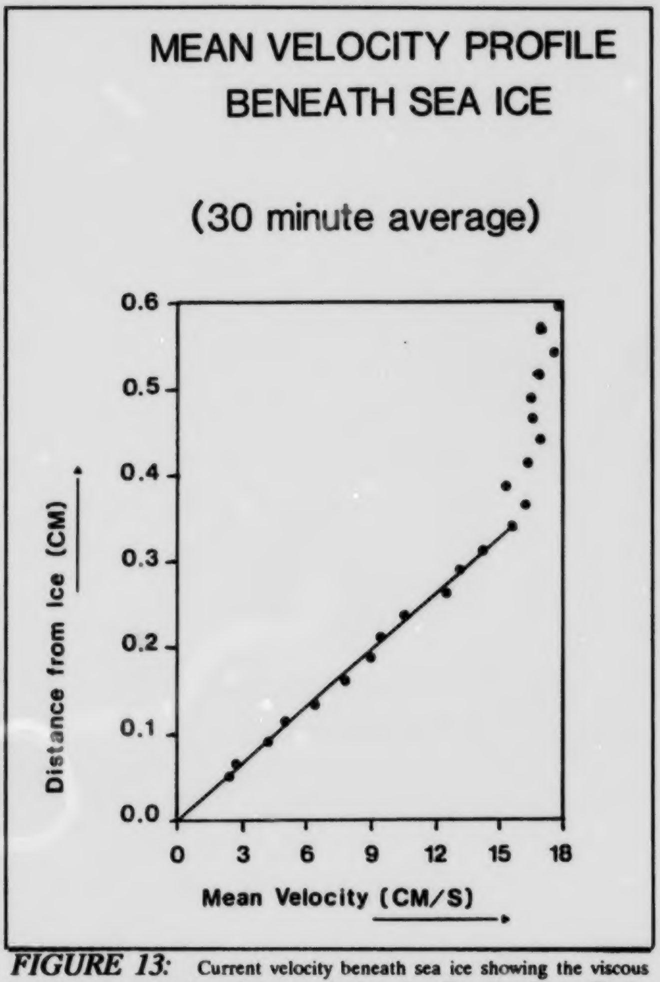


FIGURE 13: Current velocity beneath sea ice showing the viscous boundary layer (region of linear velocity). See **Boundary-Layer Physics** section for further explanation.

DISCUSSION AND FUTURE RESEARCH

How important is primary production of the ice/water interface to the total for the northern polar regions? Several years ago it was suggested that 10 g C y^{-1} m^{-2} might be a reasonable annual average for areas of one-year ice (Subba Rao and Platt 1984). Using one calculation of the area of the Arctic Ocean suitable for this kind of production (4.6%), they found that 6 • 10^6t C y^{-1} are contributed to arctic food-chains from this source. However, their estimate could be too low because the change in area of ice-covered ocean between summer and winter can be 20-25% (Weeks 1976) or 50% (Walsh and Johnson 1979) of maximum, implying a considerably greater area of annual ice potentially suitable for epontic primary production. Subba Rao and Platt also calculated that 27 g C $y^{-1}m^{-2}$ were generated by phytoplankton where arctic waters were less than 200 m deep and 9 g C for the deeper parts of the Arctic Basin, but they apparently did not ascertain how much of the total environment was suitable for phytoplankton growth. Hence, their calculation of 206 • 10^6 t C y^{-1} of phytoplankton productivity, which makes ice-algal production a trivial 3%, is much too high.

Our observations show that very little primary production takes place in the water beneath the ice; the bloom generally occurs after, or as the ice is breaking up, therefore only about 4.6% of the Arctic Basin (the same area that supports annual ice) would generate significant phytoplankton growth. Recalculation using data supplied in Subba Rao and Platt (1984), but applied to areas that have an open-water season, gives an annual phytoplankton crop of 9.54 • 10^6 t C. Epontic production then is 6/(6 + 9.54)]• 100 = 38% of the total 15.54, only slightly greater than 13 • 10^6 t originally calculated by Platt and Subba Rao (1975). All of this newly-estimated production takes place around the edges of the Arctic Basin, however, totally ignoring the 95.4% more or less continuously covered with ice. Using the only available data for this part of the northern ocean, that from Drift Station Alpha estimated to be 1 g C y^{-1} m^{-2} (English 1961), enables the further estimate of 12.5 • 10^6 t C additional phytoplankton production, but with no additional estimate for epontic production.

What is happening under the multiyear ice of the central Arctic Basin is perhaps beyond the scope of the Arctic Islands. Yet there are areas of multiyear ice within the archipelago, and, at the moment, we know virtually nothing about biological activity under such environments. Recent observations by Gulliksen and Lønne (1987) that macrofaunal amphipods are more important on multiyear ice than on new or first-year ice must indicate a favourable nutritional environment as well as more places to hide. While the light regime will not be so uniform as under one-year ice, the larger surface area should present a greater amount of suitable substrate per unit area of epontic algae. The test of such a hypothesis is probably best examined within the Arctic Islands to keep logistical costs down.

A recent theoretical maximum rate of photosynthesis by sea-ice algae of 1 g C $d^{-1}m^{-2}$ determined by Smith *et al.* (in press A) for low-snow environments will certainly not apply throughout the Arctic, but it suggests an annual total greater than the value of 10 g C $y^{-1}m^{-2}$ used by Subba Rao and Platt (1984). However the calculations are made, epontic production is not trivial and probably is at least 20 to 50% of the total, perhaps more within the archipelago.

Large-scale water movements, such as those generated by wind and tide, are important in the distribution of Arctic Ocean ice, thus they have considerable influence on where epontic production will occur. The physics of near-ice water motion may have equal or greater influence but we are just beginning to understand its importance. If ice algae can alter their physical environment (Figure 13), they might also regulate their nutrient supply making themselves less vulnerable to erosion and/or predation by grazers. We have explored how tidally-related mixing can introduce nutrients from below the euphotic zone to the immediate vicinity of the ice (Cota *et al.* 1987), but we still do not know precisely how the final few centimetres of algae mixed with ice (Figure 7) are nourished.

To the animals living directly in (micro- and meiofauna) or on (macrofaunal amphipods) the epontic algal layer, getting enough to eat would seem to present no problem, but quantitative information on feeding-rates is largely lacking. For the sub-ice pelagic animals, it is relatively easy to study their feeding on ice algae already removed from the ice, but we do not know if they can actually browse on attached algae as the larger Antarctic euphausiids (krill) apparently can (O'Brien 1987). If they do not graze directly on the under-ice surface, what percentage of their food is eroded by frictional shear of tidal currents (possibly modified by the algal exudates mentioned earlier), and how much simply drops off? Later in the spring as the ice begins to melt, ice algae may come off in sheets, some of which are still capable of photosynthesis and maintaining a colonial integrity, but their contribution to higher trophic levels is unclear.

What are the concentrations of zooplankton that might be at least partially dependent on epontic primary production? Figure 9 shows that *Pseudocalanus* sp. grew steadily during the pre-breakup spring in 1984. Over this period a maximum concentration under Resolute Passage ice of about 10^6 m^{-2} was recorded, equivalent to 7.66 g dry-weight. This is approximately equal in biomass to the maximum of more than 30 g wet-weight of ice-amphipods m^{-2} mentioned by Gulliksen and Lønne (1987), assuming that the amphipods are about 75% water (Percy and Fife 1981).

Between April 1 and mid-May the biomass of *Pseudocalanus* increased by about three times and the numbers more than doubled. The daily growth-rate was about 0.07 μg dry weight (animal)$^{-1}$ d^{-1} and the daily productivity/biomass ratio (P/B) equalled 0.01. Based on 19 separate experiments we estimated a daily carbon loss in respiration of 0.07 μg C(μg C)$^{-1}$ leading to an estimate of growth efficiency K_2 of 0.13. A daily primary production rate of 0.5 gC m^{-2}d^{-1}, from some source, would be necessary to sustain the observed growth in zooplankton over the period. Presumably most would come from the under-ice assemblage.

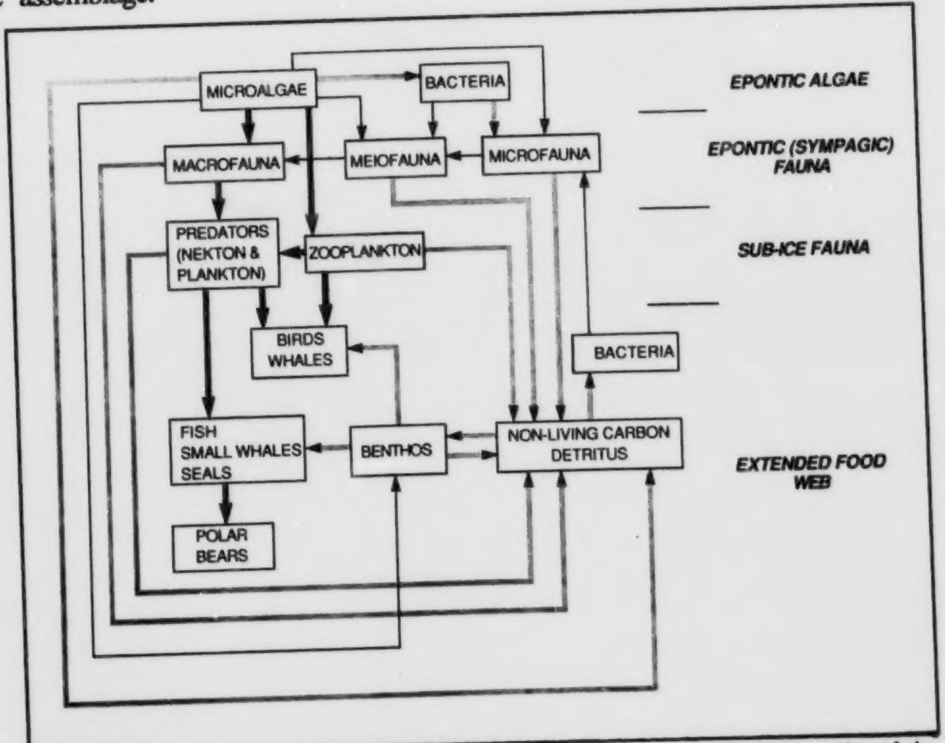

MICROALGAE
BACTERIA
EPONTIC ALGAE
MACROFAUNA
MEIOFAUNA
MICROFAUNA
EPONTIC (SYMPAGIC) FAUNA
PREDATORS (NEKTON & PLANKTON)
ZOOPLANKTON
SUB-ICE FAUNA
BIRDS WHALES
BACTERIA
FISH SMALL WHALES SEALS
BENTHOS
NON-LIVING CARBON DETRITUS
EXTENDED FOOD WEB
POLAR BEARS

FIGURE 14: Revised food-web (modified from Figure 1), showing a new interpretation of the important trophic links between the ice biota and the remaining High Arctic communities, omitting man. Energetic linkages are similar to Figure 1: (1)heavy solid arrows = observed, including our recent observations; (2) stippled arrows = inferred from other data; and (3) thin solid arrows = hypothesized.

Such a value falls within the upper range of theoretical production by epontic primary producers recently proposed by Smith *et al.* (in press A). However, as remarked earlier, the quantity of *Pseudocalanus* was dramatically higher in 1984 than in other years. In 1985, *Pseudocalanus* populations and biomass were only 15% of the previous year, and there was no clear increase in total biomass during spring. With no "production" and a generally lower biomass, the necessary primary production for maintenance would be only 0.03 gC $m^{-2}d^{-1}$. Both estimates of carbon for growth and maintenance are probably lower than reality, because we have made no correction for mortality among the zooplankton.

Our observations suggest that successive waves of zooplankton penetrate the pycnocline and approach the ice as spring progresses. While *Pseudocalanus* seems to be the most significant quantitatively, the young stages of both planktonic and benthic organisms benefit from this early ration. Our work implies that Carey's (1985) food-web is probably over-simplified (Figure 1). Probably epontic primary production and pelagic secondary production are coupled (e.g. Figure 14), allowing greater food-chain efficiency and an extended growing season, thus benefitting all arctic animals.

ACKNOWLEDGEMENTS

Our investigations in Barrow Strait over the past six years could only have been accomplished with the generous assistance of the Polar Continental Shelf Project, Energy Mines and Resources Canada, which we gratefully acknowledge. A number of colleagues have also contributed to the success of this program including: Leslie Harris, Jeff Spry, Jeff Anning, Pierre Clement, Alex Herman, Don Knox, Tim Siferd and Patti Hunter. We are also indebted to Dr. W. Lehn for accurate positioning of the 1987 camp. Finally, we are grateful to Dr. Buster Welch and his colleagues from the Freshwater Institute for their continued cooperation over several field seasons.

REFERENCES

Bradstreet, M.S.W. and W.E. Cross. 1982. Trophic relationships at High Arctic ice edges. Arctic 35:1-12.

Carey, A.G., Jr. 1985. Marine ice fauna: Arctic. In: Sea Ice Biota. Edited by: R.A. Horner. CRC Press, Boca Raton. pp. 173-190.

Conover, R.J., A.W. Bedo, A.W. Herman, E.J.H. Head, L.R. Harris, and E.P.W. Horne. (in press). Never trust a copepod - some observations on their behavior in the Canadian Arctic. Journal of Marine Science.

Conover, R.J., A.W. Herman, S.J. Prinsenberg, and L.R. Harris. 1986. Distribution of and feeding by the copepod *Pseudocalanus* under fast ice during the arctic spring. Science 232:1245-1247.

Cota, G.F. 1985. Photoadaptation of High Arctic ice algae. Nature 315:219-222.

Cota, G.F. and E.P.W. Horne. (in press). Physical control of arctic ice algal production. Nature.

Cota, G.F., S.J. Prinsenberg, E.B. Bennett, J.W. Loder, M.R. Lewis, J.L. Anning, N.H.F. Watson, and L.R. Harris. 1987. Nutrient fluxes during extended blooms of arctic ice algae. Journal of Geophysical Research 92(C2): 1951-1962.

Cross, W.E. 1982. Under-ice biota at the Pond Inlet ice edge and in adjacent fast ice areas during spring. Arctic 35:13-27.

English, T.S. 1961. Some biological oceanographic observations in the central North Polar Sea, Drift Station Alpha, 1957-1958. Arctic Institute of North America, Research Paper 13:1-80.

Environment Canada, Atmospheric Environment Service. 1986A. Climate perspective Resolute, N.W.T.

______. 1986B. Monthly radiation summary, Resolute, N.W.T.

Gosselin, M., L. Legendre, S. Demers, and R.G. Ingram. 1985. Responses of sea-ice microalgae to climate and fortnightly tidal energy inputs (Manitounuk Sound, Hudson Bay). Canadian Journal of Fisheries and Aquatic Sciences 42:999-1006.

Grainger, E.H. 1977. The annual nutrient cycle in sea-ice. In: Polar Oceans. Edited by: M.J. Dunbar. Arctic Institute of North America, Calgary. pp. 225-300.

Gulliksen, B. 1984. Under-ice fauna from Svalbard waters. Sarsia 69:17-23.

Gulliksen, B. and O.J. Lønne. 1987. Distribution, abundance and ecological importance of marine sympagic fauna ('under-ice fauna') in the Arctic. In: Marine Sciences of the Arctic and Sub-Arctic Regions. ICES Symposium 1987, Rev. No. B.

Hirche, H.-J. and R.N. Bohrer. 1987. Reproduction of the arctic copepod *Calanus glacialis* in Fram Strait. Marine Biology 94:11-17.

Horner, R. 1985A. History of ice algal investigations. In: Sea Ice Biota. Edited by: R.A. Horner. CRC Press, Boca Raton. pp. 1-19.

______. 1985B. Ecology of sea ice microalgae. In: Sea Ice Biota. Edited by R.A. Horner. CRC Press, Boca Raton. pp. 83-103.

Lewis, M.R., R.E.Warnock, and T. Platt. 1985. Absorption and photosynthetic action spectra for natural phytoplankton populations: implications for production in the open ocean. Limnology and Oceanography 30: 794-806.

Mackas, D. and R. Bohrer. 1976. Fluorescence analysis of zooplankton gut contents and an investigation of diel feeding patterns. Journal of Experimental Marine Biology and Ecology 25:77-85.

Nelson, D.M. and L.I. Gordon. 1982. Production and pelagic dissolution of biogenic silica in the southern ocean. Geochimica et Cosmochimica Acta 46:491-501.

O'Brien, D.P. 1987. Direct observations of the behavior of *Euphausia superba* and *Euphausia crystallorophias* (Crustacea: Euphausiacea) under pack ice during the antarctic spring of 1985. Journal of Crustacean Biology 7:437-448.

Percy, J.A. and F.J. Fife. 1981. The biochemical composition and energy content of arctic marine macrozooplankton. Arctic 34:307-313.

Platt, T. and D.V. Subba Rao. 1975. Primary production of marine microphytes. In: Photosynthesis and Productivity in Different Environments. Edited by: J.P. Cooper. Cambridge University Press, Cambridge, U.K. pp. 249-280.

Prinsenberg, S.J. and E.B. Bennett. 1987. Mixing and transports in Barrow Strait, the central part of the Northwest Passage. Continental Shelf Research 7:913-935.

Smith, R.E.H., J. Anning, P. Clement, and G. Cota. (in press A). The abundance and production of arctic ice algae in Resolute Passage, Canadian Arctic. Marine Ecology Progress Series.

Smith, R.E.H., P. Clement, G.F. Cota, and W.K.W. Li. 1987. Intracellular photosynthate allocation and the control of arctic marine ice algal production. Journal of Phycology 23:124-132.

Smith, R.E.H., P. Clement, and E. Head. (in press B). Biosynthesis and photosynthate allocation patterns of arctic ice algae. Limnology and Oceanography.

Subba Rao, D.V. and T. Platt. 1984. Primary production of arctic waters. Polar Biology 3:191-201.

Walsh, J.E. and C.M. Johnson. 1979. An analysis of arctic sea ice fluctuations, 1953-77. Journal of Physical Oceanography 9:580-591.

Watson, N.F., G.F. Cota, and J.L.Anning. (in press). Zooplankton variability under ice cover at a site in Barrow Strait in the Canadian Arctic. Canadian Journal of Fisheries and Aquatic Sciences.

Weeks, W.F. 1976. Sea ice conditions in the arctic. Arctic Ice Dynamics Joint Experiment Bulletin No. 34:173-205.

SURFACE TOPOGRAPHY, THICKNESS AND ICE-CORE STUDIES OF MULTIYEAR LANDFAST SEA ICE AND WARD HUNT ICE SHELF, NORTHERN ELLESMERE ISLAND, N.W.T.

Martin O. Jeffries,[1] H. Roy Krause,[2] William M. Sackinger,[1] and Harold V. Serson[3]

Abstract: Surface topography, ice thickness and the physical properties of multiyear landfast sea ice (MLSI) and ice shelves, particularly Ward Hunt Ice Shelf, are considered in this paper. The MLSI and ice shelves have an undulating topography of parallel hummocks and depressions. Measurements taken from air photographs obtained in July 1984 show that the wavelength of the undulations (hummock crest to hummock crest) on MLSI has an overall mean value of 67 m, in contrast to that of the ice shelves (251 m). An order of magnitude difference also exists between the mean thickness of MLSI and the ice shelves. In view of this, a second-order polynomial relationship between mean ice thickness and mean wavelength is suggested as a rule-of-thumb to ice thickness.

The salinity and oxygen-isotope data for ice-cores drilled in Ward Hunt Ice Shelf and various MLSI locations are presented. The oxygen isotopes are used as conservative tracers to identify fresh, brackish and sea ice. The MLSI cores contain an average of 66.3% brackish ice, 33.4% sea ice and 0.3% fresh ice. We suggest that MLSI commonly grows from brackish water that persists year-round below the ice, particularly in under-ice melt-pools that are found in inverted depressions on the bottom of the ice. West Ward Hunt Ice shelf contains a thick body of sea ice (as much as 35 m), in contrast to the east ice shelf, which is almost entirely fresh ice. We believe this is related to bottom accretion of sea ice and fresh ice associated with the flow of seawater into Disraeli Fiord, and the outflow of stratified seawater-freshwater from the fiord.

The growth of thick sea ice is discussed with reference to thermodynamic and double-diffusion models. We conclude that there is a need for field-data collection and modelling of the heat and mass-balance of thick sea ice. This is in addition to further studies of the physical-structural properties of this thick ice, particularly brackish ice, for which few data are available.

Résumé: Cette présentation traite de la topographie, de l'épaisseur et des propriétés physiques de la glace de mer côtière pluri-annuelle (GMCP) et des plates-formes de glace, en particulier la plate-forme de glace de Ward Hunt. La GMCP et les plates-formes ont une topographie ondulée en hummocks et dépressions parallèles. Les mesures tirées de photographies aériennes prises en juillet 1984 montrent que la longueur d'onde des ondulations (de crête à crête) sur la GMCP a une valeur globale moyenne de 67 m, alors qu'elle est d'environ 251 m pour les plates-formes. Il y a aussi une différence d'un ordre de grandeur entre l'épaisseur moyenne de la GMCP et celle des plates-formes. Par conséquent, on pense à une relation polynômiale de second-ordre entre l'épaisseur de glace moyenne et la longeur d'onde moyenne, comme règle empirique pour l'épaisseur de la glace.

On présentera la salinité et les données obtenues par isotopes de l'oxygène pour des carottes de glace prélevées dans la plate-forme de Ward Hunt et en divers endroits de la GMCP. Les isotopes de l'oxygène sont utilisés comme traceurs pour identifier les glaces d'eau douce, d'eau saumâtre et d'eau salées. Les carottes de GMCP contiennent en moyenne 66.3 % de glace d'eau saumâtre, 33.4 % de glace d'eau de mer et 0.3 % de glace d'eau douce. On avance l'hypothèse que la GMCP se forme habituellement à partir de l'eau saumâtre qui persiste toute l'année sous la glace, en particulier dans les mares de fonte qui se trouvent dans les dépressions inversées de la surface inférieure de la glace. L'ouest de la plate-forme de Ward Hunt se compose d'une épaisse couche de glace de mer (jusqu'à 35 m), alors l'est est presque uniquement en glace d'eau douce. Cela nous semble lié à l'accrétion par le fond de glace de mer dans le fjord Disraeli, et à la sortie du fjord d'eau de mer et d'eau douce stratifiées.

On envisagera le croissance de la glace de mer épaisse en référence aux modèles thermodynamique et de double diffusion. En conclusion, on souligne le besoin de recueillir et modéliser les données de terrain sur les bilans thermique et massique de la glace de mer épaisse, ceci en plus d'études ultérieures sur les propriétés physico-structurelles de cette glace épaisse, en particulier de la glace d'eau saumâtre, sur laquelle on a peu de données.

INTRODUCTION

The fast-ice fringe along the north coast of Ellesmere Island consists of ice shelves and multiyear landfast sea ice (MLSI). The ice shelves, particularly Ward Hunt Ice Shelf, have been the subject of occasional, intense study since the early 1950s when it was confirmed

---

[1] Geophysical Institute, University of Alaska, Fairbanks, Alaska 99775-0800, U.S.A.
[2] Department of Physics, University of Calgary, Calgary, Alberta T2N 1N4
[3] Consultant, 977 Stellycross Road, Brentwood Bay, British Columbia.

that the ice shelves were the source of ice islands (Koenig *et al.* 1952; see also Ommanney 1982A,B for extensive bibliographies of Arctic ice-shelf and ice-island research prior to 1982). On the other hand, unlike the ice shelves and ice islands, there has been very little research on the MLSI.

The ice shelves owe their origin to two primary processes: (1) the flow of glacier tongues into fiords and inlets, e.g. Milne Ice Shelf (Jeffries 1986); and (2) the in situ growth of landfast sea ice, e.g. Ward Hunt Ice Shelf (Lyons and Leavitt 1961; Lyons *et al.* 1971; Jeffries and Krouse 1984; Jeffries *et al.* 1988A). Much of the present landfast sea ice has grown to replace large areas of shelf ice lost by ice-island calving. In places, the landfast sea ice occupies the entire area of a bay, e.g. Yelverton Bay, or it is found attached to the front of ice shelves, e.g. Ward Hunt Ice Shelf and Milne Ice Shelf (Lyons and Ragle 1962; Lister 1962; Jeffries and Serson 1986; Jeffries *et al.* 1987, 1988B).

The growth of MLSI is a means by which the ice shelves regenerate and increase their lateral extent. Furthermore, present day MLSI growth might be analogous to the early growth of some Arctic ice shelves. Thus, studies of MLSI could lead to an understanding of the cycle of ice-shelf growth and disintegration, and of ice-shelf growth-history and processes. With the exception of the Markham Bay Re-entrant (Lyons and Ragle 1962; Ragle *et al.* 1964) and the Nansen Ice Plug (Serson 1972), there have been neither recent nor extensive studies of MLSI.

In spring 1982, an ice-coring program was begun on Ward Hunt Ice Shelf and adjacent areas of MLSI on the north coast of Ellesmere Island. The primary aim was to examine ice stratigraphy, with particular emphasis on salinity measurements and stable-isotope tracing, as well as interpretation of ice-growth processes and history. Detailed aspects of this work, including the field and laboratory methods have been published elsewhere (Jeffries and Krouse 1984, 1988; Jeffries *et al.* 1988A,B). This paper is both a summary of results obtained to date, and a presentation of new data on surface topography and ice thickness, and a new approach to the identification of fresh, brackish and sea ice in Ward Hunt Ice Shelf and MLSI. The results are discussed with reference to ice-growth processes associated with the flow of fresh, brackish and seawater below the ice.

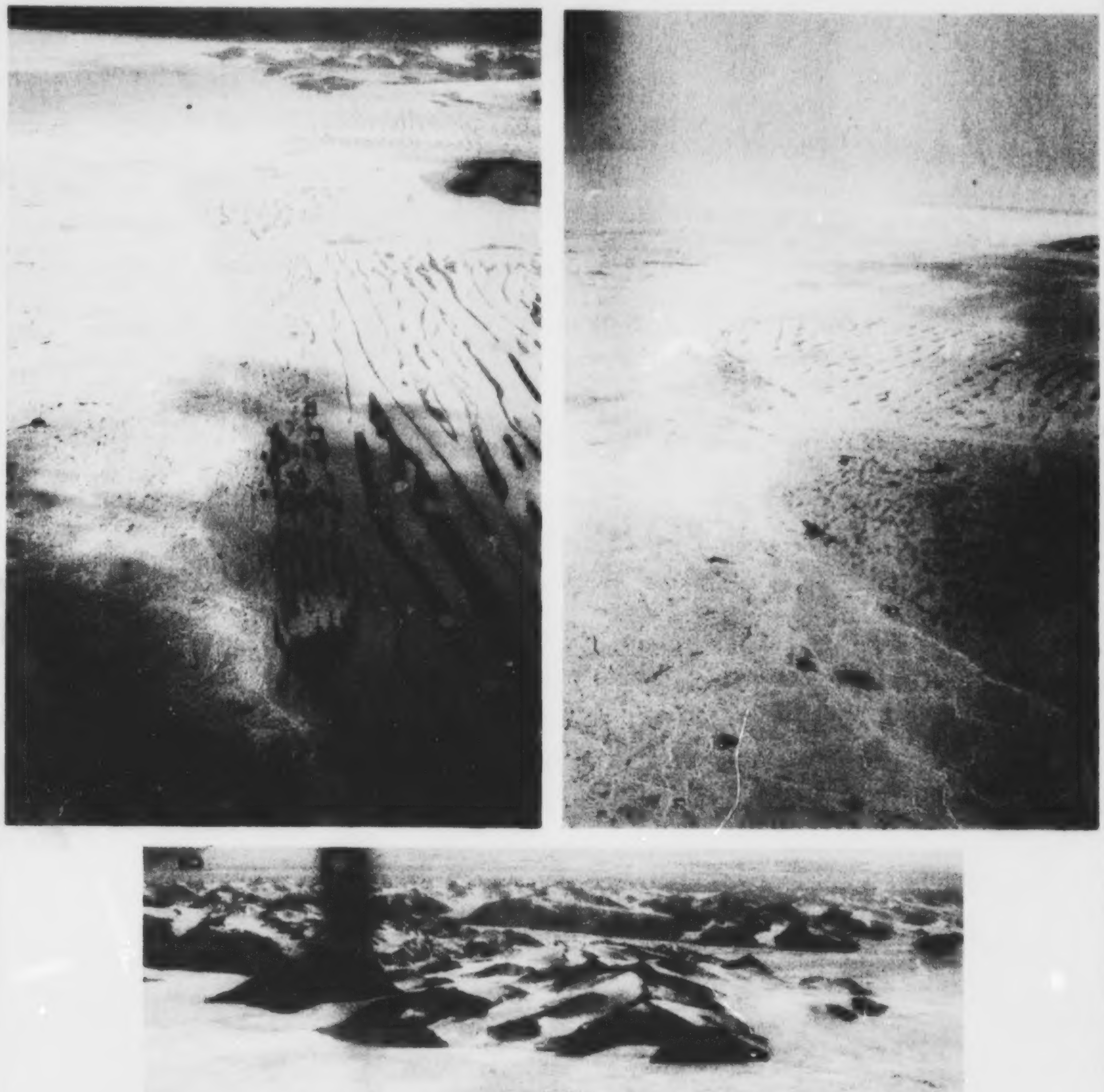


FIGURE 1: **Surface topography of multiyear landfast sea ice (MLSI) and ice shelves: Ward Hunt Ice Shelf (A); Milne Ice Shelf and Milne Re-entrant (B); Ayles Ice Shelf (C).**

SURFACE TOPOGRAPHY AND ICE THICKNESS

The ice islands that were discovered in the late 1940s and early 1950s were distinguished not only by their immense size, but also by their striking undulating surface of parallel ridges and troughs (Koenig *et al.* 1952). Commonly referred to as "rolls" (Hattersley-Smith 1957), the ridges and troughs are also an ice-shelf feature, and it was this common link that confirmed that the ice shelves were the source of ice islands (Koenig *et al.* 1952).

The rolls are most easily observed in summer when the troughs contain long, linear lakes of meltwater (Figure 1). It is also clear from Figure 1 that the MLSI has a similar undulating topography, albeit at a smaller scale than the ice shelves. The term "ridge" is somewhat ambiguous when used with reference to sea ice; thus, we prefer hummock and depression for ridge and trough respectively.

There have been no systematic studies of the origin or the perpetuation of the rolls, and it is not our purpose to discuss this. Instead, new data are presented with regard to the size of the undulations and their possible relationship to ice thickness.

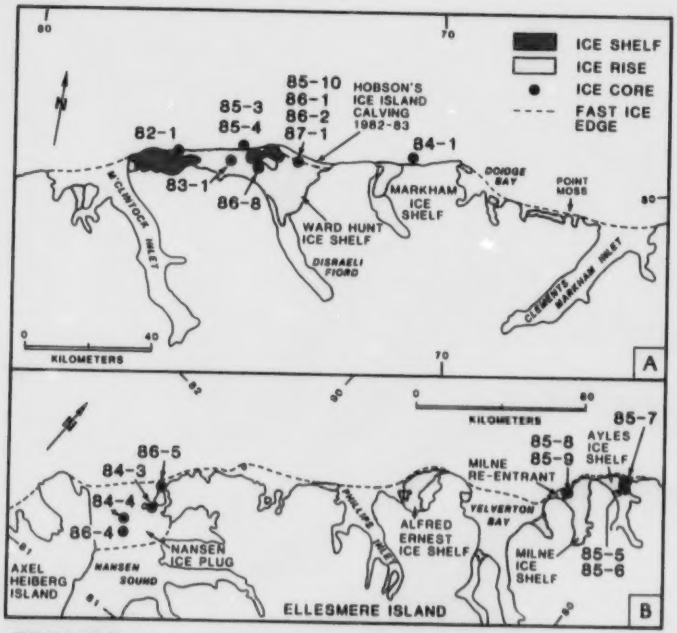

80
70
ICE SHELF
ICE RISE
ICE CORE
FAST ICE EDGE
N
85-10
86-1
86-2
87-1
HOBSON'S ICE ISLAND CALVING 1982-83
85-3
85-4
82-1
84-1
83-1
86-8
M'CLINTOCK INLET
DOIDGE BAY
POINT MOSS
MARKHAM ICE SHELF
WARD HUNT ICE SHELF
DISRAELI FIORD
CLEMENTS MARKHAM INLET
0
40
KILOMETERS
A
82
0
80
KILOMETERS
86-5
84-3
84-4
86-4
85-7
85-8
85-9
AYLES ICE SHELF
MILNE RE-ENTRANT
NANSEN ICE PLUG
AXEL HEIBERG ISLAND
NANSEN SOUND
PHILLIPS INLET
ALFRED ERNEST ICE SHELF
YELVERTON BAY
MILNE ICE SHELF
85-5
85-6
ELLESMERE ISLAND
B

FIGURE 2: Location map of the study area and ice core locations from M'Clintock Inlet to Clements Markham Inlet (A), and Nansen Sound to Ayles Fiord (B).

Surface-Topography Variations

In July 1984, we undertook an aerial photographic survey of the ice shelves and landfast sea ice from Point Moss to Yelverton Bay (Figure 2). The wavelength of the undulations (distance from hummock crest to hummock crest) was measured at five different MLSI locations to an accuracy of 5 m. The wavelength of undulations on Markham Bay Re-entrant was measured from a 1961 air photograph to an accuracy of 15 m. On the ice shelves, single locations were chosen on Ayles Ice Shelf and Milne Ice Shelf, as well as four different locations on Ward Hunt Ice Shelf.

The measurement data are summarized in Table 1. There is an order of magnitude difference between the overall mean wavelength on MLSI and on the ice shelves. Also, there is a greater variability on the ice shelves than on the MLSI.

There is a limited amount of relative-relief data, i.e., the vertical distance from hummock crest to depression bottom. Data from our observations and measurements are given in Table 2. In addition to actual measurements taken at three ice-core sites on MLSI, our experience in traveling over MLSI by snowmobile indicates that MLSI has a very low relative relief compared to the ice shelves.

Ice Thickness and Bottom Topography

Ground observations and air-photograph analysis indicate that large areas of MLSI are undeformed, largely due to growth in sheltered locations where pack-ice motion is minimized (Figures 1B,C) (Jeffries *et al.* 1987, 1988B). At these locations the ice has a gentle, undulating topography. At more exposed locations, e.g. the front of West Ward Hunt Ice Shelf (cores 85-3 and 85-4, Figures 1A, 2A), the ice is commonly deformed, with a rough, hummocky topography of old, weathered pressure ridges.

The mechanical deformation of pack ice results in considerable thicknesses (>5 m). In contrast, the equilibrium-thickness of undeformed multiyear pack-ice floes is 2.5-5 m (Maykut and Untersteiner 1971). Data from undeformed MLSI (except that at the front of Ward Hunt Ice Shelf) ice-cores and boreholes drilled through MLSI (Table 2) suggests that the ice thickness at least equals, and commonly exceeds the equilibrium thickness of multiyear pack ice. A more extensive ice-thickness measurement program is required to confirm this.

In addition to the unusual ice-surface topography, Jeffries *et al.* (1988B) present evidence that deformed and undeformed MLSI has a pronounced bottom topography which mirrors the surface topography. For example, at the sites of ice cores 85-3 and 85-4 (Ward Hunt MLSI), 85-5 and 85-6 (Ayles MLSI) and 85-8 and 85-9 (Milne Re-entrant) (Figure 2), allowing for the relative surface relief (Table 2), the bottom of the hummock ice is 0.85 m, 1.865 m and 1.74 m, respectively, deeper than the bottom of adjacent depression ice. These data are from single locations on each MLSI sheet and it remains to be determined

TABLE 1: MEASUREMENTS OF THE WAVELENGTH (m) OF THE UNDULATING SURFACE TOPOGRAPHY OF MLSI AND SHELF ICE.

LOCATION	MINIMUM	MAXIMUM	MEAN (± 1S.D.)	NUMBER OF MEASURE-MENTS
		MLSI		
Doidge Bay	27	70	43±8	85
Ward Hunt Ice Shelf	25	105	55±15	63
Ayles Fiord	45	121	79±17	138
Milne Re-entrant	40	127	80±21	128
Yelverton Bay	30	85	59±10	130
Markham Bay[1] Re-entrant	40	120	71±16	89
		OVERALL	67±15	633
		SHELF ICE		
Ward Hunt Ice Shelf East	87	355	212±42	84
Ward Hunt Ice Shelf South	110	398	225±69	111
Ward Hunt Ice Shelf West	110	382	258±64	101
Ward Hunt Ice Shelf External West	138	440	280±53	66
Ayles Ice Shelf	108	311	211±48	80
Outer Milne Ice Shelf	135	450	330±62	86
Ice Island T-3[2]	230	260	245	-
		OVERALL	51±57[3]	528

---

[1] Markham Bay Re-entrant formed at the east end of Ward Hunt Ice Shelf prior to 1962-63. The wavelength measurements were made on a 1960 air photograph.

[2] Data for T-3 are from Crary (1960).

[3] Overall mean excludes the T-3 data.

TABLE 2: DATA ON RELATIVE SURFACE RELIEF AND ICE THICKNESS OF MLSI AND SHELF ICE.

LOCATION	RELATIVE RELIEF (m)	ICE THICKNESS (m)	SOURCE
Ice core 84-1	N/A	3.77 Hummock (H)	Ice core
Ice core 85-3	1.53	7.62 Depression (D)	Ice core
Ice core 85-4		10.00 (H)	Ice core
Ice core 85-5	0.545	4.22 (D)	Ice core
Ice core 85-6		6.63 (H)	Ice core
Ice core 85-7	N/A	6.26 (D)	Ice core
Ice core 85-8	0.82	9.80 (H)	Ice core
Ice core 85-9		7.24 (D)	Ice core
Ice core 84-3	N/A	2.24	Ice core
Ice core 84-4	N/A	3.75	Ice core
Ice core 86-4	N/A	5.53	Ice core
Ice core 86-5	0.70 m	3.06 (D)	Ice core
M'Clintock Inlet	N/A	7.92	Borehole[1]
Yelverton Bay	N/A	6.50 (mean)	Boreholes (>200)
Markham Bay Re-entrant		11.00	Boreholes (Lyons and (Ragle 1962)
Ward Hunt Ice Shelf (1)		42.50[2] (mean)	Boreholes[1]
Ward Hunt Ice Shelf (2)	2-7.5 m	47.00	Ice core, Lyons *et al.* (1971)
Ward Hunt Ice Shelf (3)		44.75	Ice core 83-1, ice temperature
Ward Hunt Ice Shelf (4)		50.66	Ice core 82-1, ice temperature
Outer Milne Ice Shelf	5-7.5 m	75.00 (mean)	Radio-echo, Narod *et al.* (in press)
Ice Island T-3	N/A	48.00 (mean)	Seismic Crary (1958)

---

[1] Personal communication, R. Verrall, Defence Research Establishment Pacific.
[2] Thickness data for East Ward Hunt Ice Shelf is actually from Hobson's Ice Island, which calved from the eastern ice shelf in 1982-1983 (Jeffries and Serson 1983).
(1) to (4) See Table 1.

whether the inverted bottom-side depressions are, like their surface counterparts, long and linear features.

Hattersley-Smith (1957) proposed that the surface topography of the ice shelves was also mirrored by an inverted topography at the undersurface. Recently, however, airborne radio-echo sounding of Outer Milne Ice Shelf, where the surface depressions are particularly deep (Table 2), has shown that the surface topography has little or no bottom-side expression (Narod *et al.*, in press).

Radio-echo sounding of ice thickness has been used successfully on Milne Ice Shelf and East Ward Hunt Ice Shelf. Outer Milne Ice Shelf has a mean thickness of 75 m, and East Ward Hunt Ice Shelf a thickness of 45-50 m (Narod *et al.*, in press). The latter thickness is corroborated quite well by Hobson's Ice Island, which calved from East Ward Hunt Ice Shelf (Figure 2A) (Jeffries and Serson 1983), and has a mean thickness of 42.5 m (Table 2). Radio-echo sounding of the remainder of Ward Hunt Ice Shelf has had mixed success, largely due to the presence of saline ice (Figure 8) (Hattersley-Smith *et al.* 1969; Narod *et al.*, in press). Spot-depths for West Ward Hunt Ice Shelf have been calculated from ice-temperature profiles at the site of ice cores 82-1 and 83-1 that were drilled for this study (Figure 2A; Table 2). Lyons *et al.* (1971) drilled a 47 m ice core through the ice shelf 5 km southwest of Ward Hunt Island (Figure 2A, Table 2).

Relationship between Ice Thickness and Surface Topography

The data show that there is an order of magnitude difference between the thickness of the ice shelves and MLSI, and also between the wavelength of the undulations on each type of ice. Does this, then, suggest a relationship between ice thickness and surface topography geometry? The data were analyzed and the best relationship was found to be a second-order polynomial between mean ice thickness and mean wavelength (Figure 3). For MLSI, the mean ice-thickness data for Milne Re-entrant,

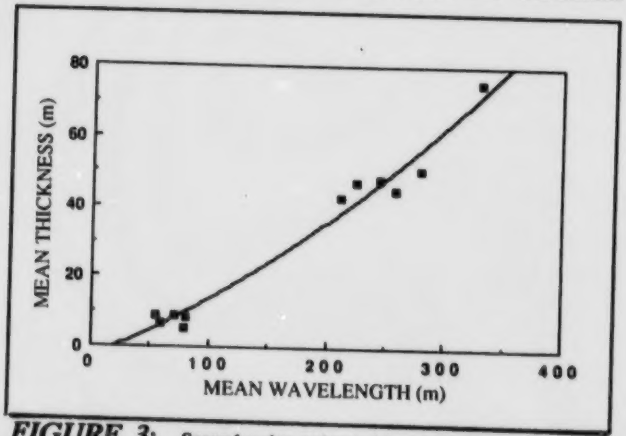


FIGURE 3: Second-order polynomial relationship between ice thickness and mean wavelength of surface undulations of MLSI and ice shelves. The line is represented by the equation $y=0.1392X + 0.0002826X^2 - 2.805$m (y:mean thickness. X:mean wavelength).

Ayles Fiord and the ice at the front of Ward Hunt Ice Shelf were taken as the mean of the thickness of adjacent hummocks and depressions, while the spot-depth for Markham Bay Re-entrant was taken as the mean thickness (Table 2). Likewise, the spot-depths for West and South Ward Hunt Ice Shelf (Table 2) were assumed to be the mean thickness.

This relationship (Figure 3) remains to be proven and would require an extensive ice-thickness measurement program. However, in view of the difficulties associated with radio-echo sounding and the probably high cost of a ground-based borehole drilling program, the relationship based on the available data might serve as a useful rule-of-thumb for the approximate determination of ice thickness. Thus, in the case of Doidge Bay MLSI and Ayles Ice Shelf (for which ice-thickness data are unavailable), the mean wavelength of the surface undulations (Table 1) indicates a mean ice thickness of 3.7 m and 39.1 m, respectively. It is interesting to note that observations made by one of us (H.V.S.) in May 1969 in Doidge Bay indicated an ice thickness of about 4 m, close to the 3.7 m derived according to the mean wavelength of the undulations.

SALINITY AND OXYGEN-18 CONTENT OF WARD HUNT ICE SHELF AND MLSI ICE CORES

The physical and structural properties of ice are primarily a function of the water properties at the time of ice growth, and not diagenetic (post-growth) processes. For freshwater ice and sea ice the physical and structural properties have been studied extensively and are, therefore, quite well known. In contrast, the physical and structural properties of brackish ice have received very little attention; hence, it is difficult to recognize brackish ice on the basis of ice structure alone. Using salinity and stable-isotope data, brackish ice was identified in Ward Hunt Ice Shelf, near Ward Hunt Island (Lyons *et al.* 1971). With this in mind, salinity and stable-isotope measurements were made on our ice cores from Ward Hunt Ice Shelf and the MLSI. In this section, the principles behind the application of stable isotopes to the recognition of fresh, brackish and sea ice are described. Then, the results are presented and discussed.

Oxygen-18 as a Conservative Tracer for Sea-Ice Studies

The loss of brine from sea ice at the time of growth and during subsequent aging means that ice salinity is not a conservative tracer for the purpose of identifying fresh, brackish and sea ice. On the other hand, the stable isotopes of ice/water are conservative tracers, since the stable isotope content of the ice remains almost the same as that of the water. Experimental studies of oxygen-isotope fractionation during freezing show that the fractionation factor (α) has a maximum value of 1.003 (O'Neil 1968). That is, during freezing the ice is enriched in ^{18}O by as much as 3°/oo relative to the water. This is a small fractionation compared to the brine-loss from sea ice.

For the purpose of simplicity, an α-value of 1.003 is assumed for this study. Thus, after subtracting 3°/oo from a given ice δ value, the δ value of the parent water is obtained. Jeffries and Krouse (1988) suggest that meltwater infiltration at the surface of MLSI is minimal. For the purpose of this study, δ values from the uppermost 0.5 m of ice are excluded to allow for possible infiltration of ^{18}O-depleted meltwater and alteration of original δ values, and the exclusion of refrozen melt-pools.

To obtain the water salinity from the ice/water $\delta^{18}O$ values it is necessary to know the salinity - $\delta^{18}O$ relationship in the parent water. In Disraeli Fiord and Milne Fiord, where freshwater-seawater stratification exists, owing to the damming action of Ward Hunt Ice Shelf and Milne Glacier (Figure 2B) (Keys 1978; Jeffries 1985), salinity and $\delta^{18}O$ are related as follows:

$$[1] \quad \text{Salinity} = 1.17\ \delta^{18}O + 34.51°/oo$$

Assuming that this relationship applies to the entire study area (Figure 2), then, the water $\delta^{18}O$ value (derived from the ice $\delta^{18}O$ value as explained in the previous paragraph) can be used in equation [1] to determine the water salinity that prevailed at the time of growth.

Having determined the water salinity and ^{18}O content, there remains the question of what criteria to use to differentiate between fresh, brackish and seawater. In this region the freshwater is derived mainly from glacier and snow-fed rivers and streams flowing into fiords and inlets. The salinity of the river and streamwater has not been measured directly, but "freshwater" at the surface of Disraeli and Milne fiords has a salinity of 1.07°/oo and 0.13°/oo respectively (Jeffries 1985). These data agree with Mason and Moore (1982), who note that river-water salinity rarely exceeds 1.0°/oo. For this study, the upper limit of the freshwater salinity is taken as 1.0°/oo.

The lower limit of the seawater salinity is assumed to be 24.7°/oo based on the knowledge that freezing kinetics and ice-growth processes change at salinities exceeding 24.7°/oo (Weeks and Ackley 1982). Table 3 summarizes the freshwater, brackish water and seawater categories according to the range of water salinity and $\delta^{18}O$ values, and ice $\delta^{18}O$ values. On this basis it is now possible to identify fresh, brackish and sea ice directly from the ice $\delta^{18}O$ values.

TABLE 3: FRESH, BRACKISH AND SEA WATER/ICE CLASSIFICATION ACCORDING TO WATER SALINITY AND $\delta^{18}O$ VALUES, AND ICE $\delta^{18}O$ VALUES.

WATER/ICE TYPE	WATER SALINITY (°/oo)	WATER $\delta^{18}O$ (°/oo)	ICE $\delta^{18}O$ (°/oo)
Sea	≥ 24.7	≥ 8.5	≥ 5.5
Brackish	1.01 to 24.69	-28.6 to -8.5	-25.6 to -5.5
Fresh	≤ 1.00	≤ -28.7	≤ -25.7

Before presenting the results, a short explanation of the ^{18}O content of seawater and sea ice is warranted. On a global basis, seawater has a mean $\delta^{18}O$ value of ~0.0°/oo (Craig 1961), with some slightly negative deviations arising from local input of meteoric water (meteoric water is water that has been involved in recent atmospheric circulation and has a $\delta^{18}O$ value less than zero). In the Arctic Ocean, where meteoric water $\delta^{18}O$ values are very negative, the surface waters have a $\delta^{18}O$ range of -4.5°/oo to +0.3°/oo (Vetshteyn *et al.* 1974; Östlund and Hut 1984), due to mixing of meteoric water and seawater. Assuming maximum isotopic fractionation on freezing, the aforementioned values correspond to ice $\delta^{18}O$ values of -1.5°/oo to +3.3°/oo. Values similar to these are found in MLSI. But, as we will show, many ice $\delta^{18}O$ values in MLSI are much more negative, and in some instances are close to the mean $\delta^{18}O$ value (-31.3°/oo) of precipitation in this region (Jeffries and Krouse 1987).

Fresh, Brackish and Sea Ice in MLSI

Twelve ice cores have been drilled in MLSI at a number of different locations throughout the study area (Figure 2). In many cases the ice cores were drilled in recognizable hummocks and depressions but, because of the snow-covered, low relative relief, it was not always possible to identify the topographic locations. The salinity and isotope data for each core are summarized in Table 4. It is noted that $\delta^{18}O$ range includes values close to 0.0°/oo, indicative of seawater, and very negative $\delta^{18}O$ values which indicate a considerable meteoric water input to the water-ice system. The mean $\delta^{18}O$ values all fall in the brackish ice range, with two exceptions (ice cores 84-4 and 86-4).

TABLE 4: SUMMARY OF ICE SALINITY AND ICE $\delta^{18}O$ VALUES IN MLSI.

ICE CORE[1]	SALINITY RANGE (°/oo)	MEAN SALINITY (°/oo)[2]	$\delta^{18}O$ RANGE (°/oo)	MEAN $\delta^{18}O$ (°/oo)[2]
84-1 (H)	0.01 to 2.09	0.85 ± 0.41	-23.8 to -2.9	-14.0 ± 6.8
84-3	0.01 to 1.93	0.37 ± 0.33	-16.4 to -9.6	-12.9 ± 1.8
84-4	0.01 to 3.41	0.74 ± 0.46	-10.9 to +0.7	-3.9 ± 3.3
85-3 (D)	0.18 to 4.39	1.26 ± 0.45	-24.5 to -0.7	-10.9 ± 8.3
85-4 (H)	0.03 to 12.06	2.92 ± 1.54	-20.7 to -1.4	-5.2 ± 4.3
85-5 (D)	0.01 to 0.22	0.08 ± 0.06	-22.4 to -13.8	-18.2 ± 2.9
85-6 (H)	0.01 to 3.84	0.60 ± 0.58	-22.9 to -1.4	-15.2 ± 7.7
85-7 (D)	0.01 to 3.53	1.21 ± 0.73	-29.9 to -1.6	-17.3 ± 6.3
85-8 (H)	0.03 to 4.54	1.61 ± 0.97	-22.7 to -2.8	-9.5 ± 5.6
85-9 (D)	0.03 to 3.30	1.07 ± 0.73	-22.0 to -6.3	-13.8 ± 5.1
86-4	0.16 to 2.49	0.74 ± 0.46	-11.0 to +0.2	-2.9 ± 3.2
86-5 (D)	0.22 to 8.87	1.50 ± 1.52	-19.0 to -2.7	-9.6 ± 4.5

[1] H and D denote hummock and depression respectively.
[2] Mean values are expressed with ±1 Standard Deviation.

The amount of fresh, brackish and sea ice in each MLSI core is shown in Figure 4. On the basis of these 12 ice cores, MLSI has an overall composition of 66.3% brackish ice, 33.4% sea ice, and 0.3% fresh ice. However, there is some variation from location to location. Some particular features are:

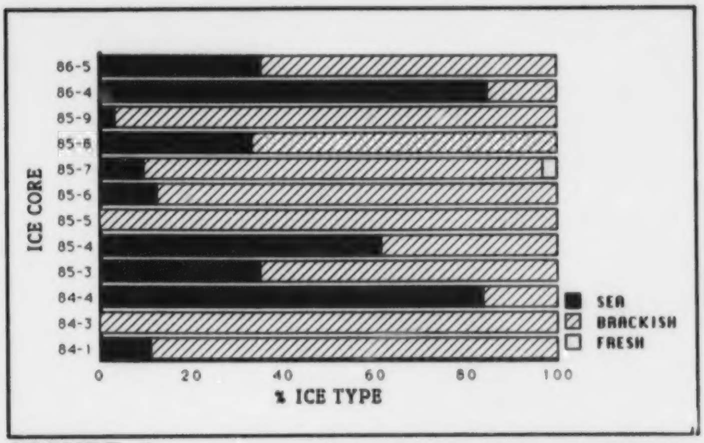


FIGURE 4: **Percentages of fresh, brackish and sea ice in MLSI cores according to ice $\delta^{18}O$ values.**

(1) Where the ice cores have been drilled in adjacent hummocks and depressions, the depression ice cores contain a greater proportion of brackish ice (Figure 4; ice cores 85-3, 85-4, 85-5, 85-6, 85-8 and 85-9). In consequence, depression ice has a lower salinity and ^{18}O content than hummock ice (Table 4).

(2) Two ice cores (84-3 and 85-5) are composed entirely of brackish ice (Figure 5).

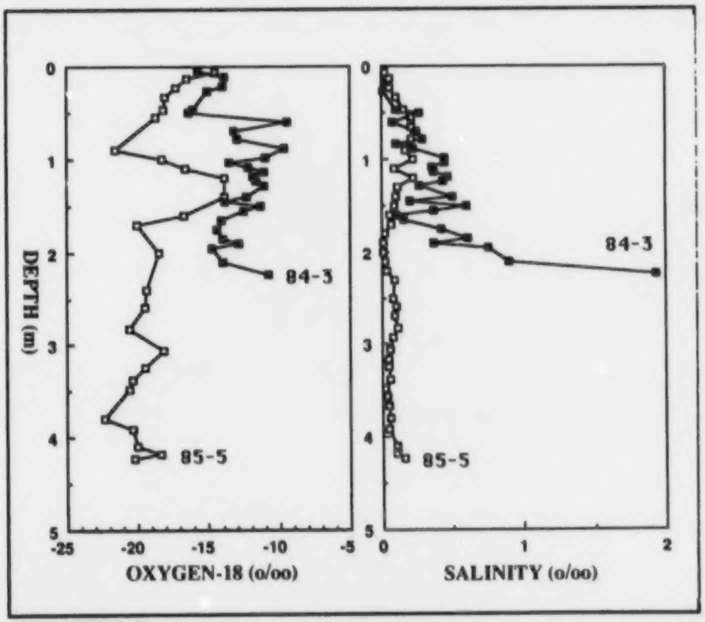


FIGURE 5: **Oxygen-18 and salinity profiles in brackish ice cores 84-3 and 85-5.**

(3) Not one ice core is composed entirely of sea ice, and we note that the two ice cores with the greatest proportion of sea ice are both in the Nansen Ice Plug (84-4, 86-4; Figure 2B).

(4) Deformed MLSI at the front of Ward Hunt Ice Shelf (Figure 2A) contains the most saline ice, but brackish ice also occurs here; at the bottom of the hummock and throughout almost the entire thickness of the depression (Figure 6).

West Ward Hunt Ice Shelf

The data for West Ward Hunt Shelf are from four ice cores (Figure 2A). Ice cores 82-6 and 83-9 were drilled at the crests of hummocks in a surface exposure of basement ice mapped by Lyons *et al.* (1971). Basement ice is ice that has accreted at the base of the ice shelf. Ice core 86-8 was drilled at the bottom of a depression in the region southwest of Ward Hunt Island (Figure 2A), where brackish ice was identified by Lyons *et al.* (1971). Ice core 83-1 was drilled at the crest of a hummock, about 9 km west of Ward Hunt Island.

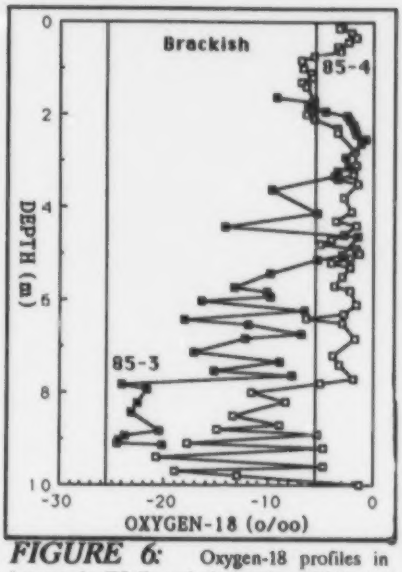


FIGURE 6: Oxygen-18 profiles in hummock (85-4) and depression (85-3) ice cores, MLSI at the front of Ward Hunt Ice Shelf. Note that in each core there is a sharp decrease in δ^{18}O values at a depth of 7.9 m.

The salinity and isotope data for each of the four ice cores are summarized in Table 5, and the amounts of fresh, brackish and sea ice in each core are shown in Figure 7. Ice cores 82-6 and 83-9 are composed entirely of sea ice. Ice core 83-1 is composed almost entirely of sea ice, with small, almost equal amounts of fresh and brackish ice. Ice core 86-8 is composed almost entirely of brackish ice; the amounts of each ice-type in core 86-8 are similar to MLSI (Figure 4).

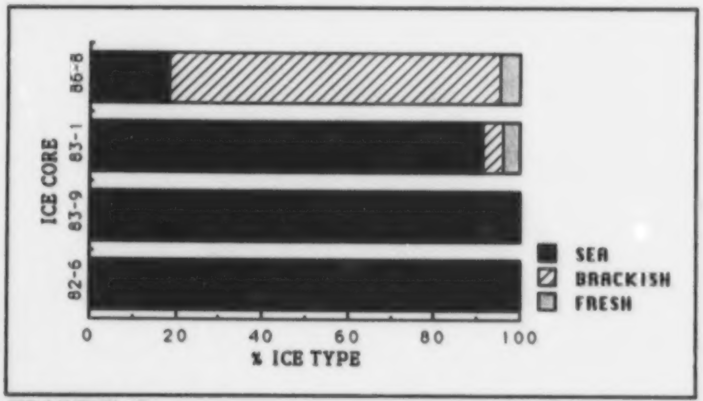


FIGURE 7: Percentage of fresh, brackish and sea ice in ice cores from West Ward Hunt Ice Shelf.

Ice core 83-1 is the longest of the four ice cores drilled in West Ward Hunt Ice Shelf, but it was not drilled right through the ice. Salinity and δ^{18}O profiles show that there are four distinct strata at this location (Figure 8). Stratum 1 is not considered here as it is the product of surface accumulation of snow and ice, not of bottom accretion. Strata 2 and 4 (Figure 8) are

TABLE 5: SUMMARY OF ICE SALINITY AND ICE $\delta^{18}O$ VALUES IN WEST WARD HUNT ICE SHELF ICE CORES.

ICE CORE	SALINITY RANGE (^{o}/oo)	MEAN SALINITY (^{o}/oo)	δ^{18}O RANGE (^{o}/oo)	MEAN δ^{18}O (^{o}/oo)
82-6 (3.49 m)	0.80 to 3.44	2.13 ± 0.51	-0.9 to +0.7	-0.14 ± 0.5
83-9 (2.06 m)	1.98 to 3.40	2.61 ± 0.45	-1.0 to +0.9	0.0 ± 0.6
86-8 (10.28 m)	0.05 to 2.14	0.70 ± 0.68	-26.6 to -0.4[1]	-14.2 ± 8.2
83-1 (31.79 m)				
Stratum 2	0.28 to 3.68	2.12 ± 0.61	-2.3 to 0.5	-1.1 ± 0.5
Stratum 3	0.04 to 0.39	0.18 ± 0.11	-26.6 to -22.1	25.5 ± 1.6
Stratum 4A	1.20 to 3.89	2.30 ± 0.62	-2.1 to 0.0	-1.3 ± 0.4
Stratum 4B	2.03 to 11.34	8.22 ± 3.81	-1.7 to 0.7	-0.5 ± 0.8

[1] Lyons et al. (1971) published three salinity -δ^{18}O values for brackish ice (0.32^{o}/oo and -21.6^{o}/oo, 0.37^{o}/oo and -13.2^{o}/oo, 0.26^{o}/oo and -17.5^{o}/oo). These values fall well within the range of values found in ice core 86-8.

sea-ice layers, as shown by the $\delta^{18}O$ and salinity values (Table 5). The salinity and $\delta^{18}O$ values of ice cores 82-6 and 83-9 are similar to those of Strata 2 and 4, and all this ice is classified as 'saline basement ice' (Jeffries *et al.* 1988A).

On the basis of ice salinity, Stratum 4 has been divided, with Stratum 4B being more saline than Stratum 4A (Table 5). Sixty-eight hours after drilling had ceased at a depth of 31.79 m, brine had upwelled in the borehole to a level of 25.63 m. This suggests considerable brine movement at these depths and the high ice-salinities in Stratum 4B are probably related to this phenomenon. Also, high levels of thermonuclear tritium have

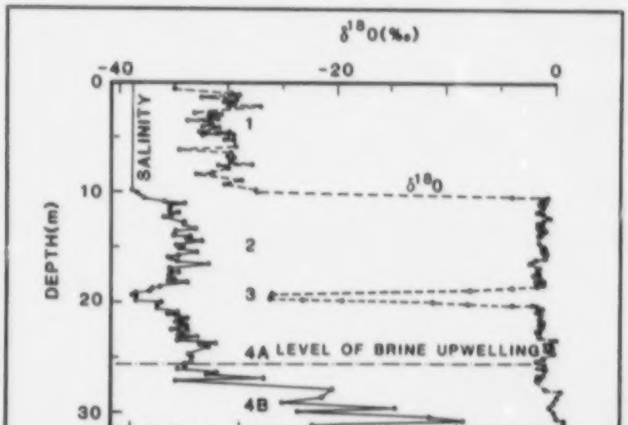


FIGURE 8: Salinity and $\delta^{18}O$ profiles in ice core 83-1, West Ward Hunt Ice Shelf (Jeffries et al. 1988A) (Reproduced by courtesy of the International Glaciological Society from Annals of Glaciology 10, p. 70, Figure 2).

levels of thermonuclear tritium have been found in Stratum 4B suggesting: (1) recent (post-1963) bottom accretion of sea ice; and (2) that brine in Stratum 4B is from deeper in the ice shelf at this location (Jeffries *et al.* 1988A). It was noted earlier that ice temperatures indicate a total ice thickness of almost 45 m at the site of ice core 83-1; the top of Stratum 4 is at a depth of 20.18 m, hence the sea ice might be as much as 25 m thick.

Strata 2 and 4 are separated by a narrow layer of low salinity, low δ^{18}O ice (Figure 8). This layer, Stratum 3, is composed of fresh and brackish ice (Table 5; Figure 7). This layer has been termed 'non-saline basement ice' (Jeffries *et al.* 1988A). The similarity between the δ^{18}O values and salinity of Strata 2 and 4, and the thinness of Stratum 3, suggest that the accretion of the latter was a relatively brief interruption of the growth of the sea ice. In the absence of Stratum 3, the sea-ice layer would be as much as 35 m thick.

East Ward Hunt Ice Shelf

The data for East Ward Hunt Ice Shelf are from four ice cores, all drilled in Hobson's Ice Island (Figure 3A) - one of a number of ice islands that calved from East Ward Hunt Ice Shelf in 1982-1983 (Jeffries and Serson 1983). Of the four ice cores, only 86-2 was drilled in a depression.

The specific electrical conductivity (SEC) and ^{18}O data are summarized in Table 6. In contrast to most of the ice in West Ward Hunt Ice Shelf, the ice cores have δ^{18}O values that are close to those of local precipitation, with SEC/salinity values that are 2-3 orders of magnitude lower than those in the West Ice Shelf. On the basis of the δ^{18}O values, the ice cores are almost wholly composed of fresh ice, with the exception of 86-1 and 86-2, which contain a small amount of brackish ice (Figure 9). SEC and δ^{18}O profiles in ice core 87-1 are shown in Figure 10. Tritium activity in ice core 87-1 has yet to be measured; however,

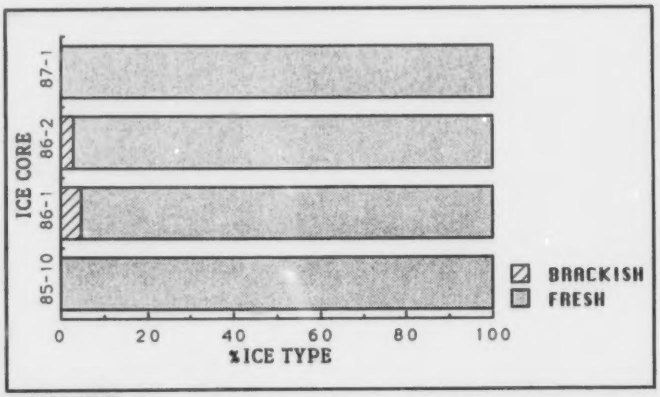


FIGURE 9: **Percentages of fresh and brackish ice in ice cores from East Ward Hunt Ice Shelf.**

in ice core 85-10 (drilled through the entire thickness of Hobson's Ice Island), high levels of tritium were found in the lowermost 5 m of ice.

TABLE 6: SUMMARY OF SPECIFIC ELECTROLYTIC CONDUCTIVITY (SEC) AND ^{18}O CONTENT OF ICE CORES IN EAST WARD HUNT ICE SHELF/HOBSON'S ICE ISLAND.

ICE CORE	SEC RANGE ($\mu S\ cm^{-1}$)	MEAN SEC ($\mu S\ cm^{-1}$)	$\delta^{18}O$ RANGE (°/oo)	MEAN $\delta^{18}O$ (°/oo)
85-10 (42.06 m)	2.18 to 32.80[1]	7.16 ± 4.35	-34.1 to -25.6	-29.8 ± 1.8
86-1 (38.67 m)	1.52 to 252.0	11.55 ± 32.76	-33.8 to -24.1	-29.5 ± 1.8
82-2 (33.97 m)	1.05 to 274.0	6.33 ± 25.42	-34.6 to -24.5	-29.8 ± 1.9
87-1 (38.80 m)	1.12 to 10.12	3.30 ± 1.51	-32.6 to -26.1	-29.6 ± 1.6

[1] A salinity of 0.1°/oo is equivalent to a SEC value of ~165.0 $\mu S cm^{-1}$.

FRESH, BRACKISH AND SEA-ICE GROWTH BENEATH MLSI AND WARD HUNT ICE SHELF

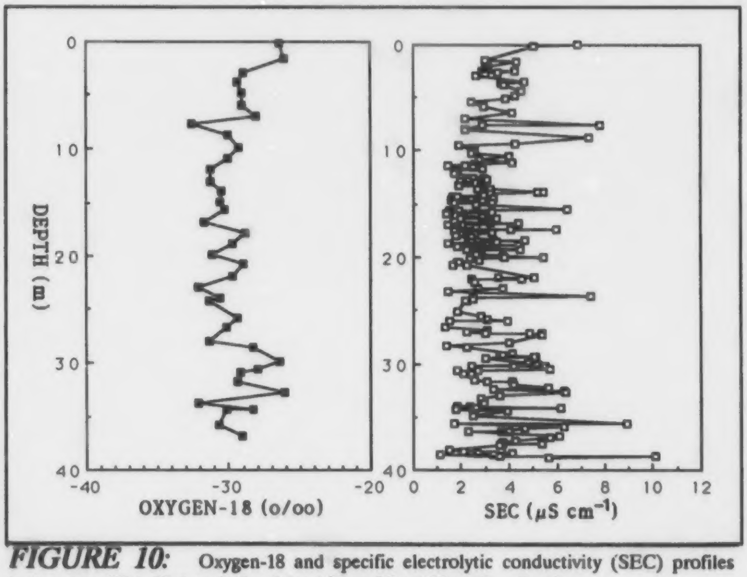


FIGURE 10: Oxygen-18 and specific electrolytic conductivity (SEC) profiles in ice core 87-1, Hobson's Ice Island/East Ward Hunt Ice Shelf.

The analysis of ice cores drilled in Ward Hunt Ice Shelf indicates a considerable contrast between ice-types found in the west shelf and the east shelf. The predominance of sea ice and fresh ice in the west and east shelf, respectively, is, in turn, a sharp contrast to the MLSI which is predominantly brackish ice. In this section, the processes responsible for these contrasts will be discussed briefly, with particular emphasis on ice growth arising from water stratification associated with under-ice melt-pools and floating ice dams.

Under-Ice Melt Pools and MLSI Growth

If, as we believe, there are inverted depressions on the bottom of MLSI, then there is a potential for the formation of under-ice melt-pools. This situation, where a layer of low-salinity water floats upon a seawater layer and under the ice has been observed quite often below pack-ice floes (Untersteiner and Badgley 1958; Hanson 1965). It has not been directly observed below MLSI, but it is believed to be quite common (Jeffries and Krouse 1988). This is supported further by data from this study.

In an under-ice melt-pool, with each water layer very near freezing, heat transfer generates ice, either directly or from buoyant supercooled water (Martin and Kauffman 1974). The ice growth occurs in the low-salinity water layer, which must also have negative $\delta^{18}O$ values; hence, the ice has negative $\delta^{18}O$ values and low salinity. If the low-salinity, ^{18}O-depleted water is confined to the inverted depressions then, as we have observed, the depression ice will be less saline and have more negative $\delta^{18}O$ values than hummock ice.

Brackish ice is apparently more common in depressions than hummocks, but it is found in hummocks. This suggests that water stratification is not confined to inverted depressions, but can exist beneath the entire ice sheet. Since the water salinity and ^{18}O content is seasonally variable, associated with ice and snow-melt runoff in summer, water stratification under the entire ice sheet will most likely occur in summer. The seasonality of water properties gives rise to seasonal or annual layers in the MLSI (Jeffries and Krouse 1988).

The seasonality of water properties is not always a brackish water-seawater alternation. Apparently, MLSI can be underlain year-round by brackish water, giving rise to 100% brackish ice, e.g. ice cores 84-3 and 85-5. Further evidence of the year-round persistence of brackish water was obtained at the site of ice core 85-5, where a sample of water that entered the borehole on completion of drilling had a $\delta^{18}O$ value of -24.6°/oo, i.e. brackish water. This occurred in early May, before the onset of melting and runoff.

On the other hand, at some locations the MLSI is clearly underlain by seawater most of the time, e.g. the Nansen Ice Plug (Figure 2B; ice cores 84-4 and 86-4). Water that entered the 86-4 borehole had a $\delta^{18}O$ value of -2.7°/oo. In contrast, water that entered the borehole in deformed MLSI at the site of ice core 85-3 (Figure 2A) had a $\delta^{18}O$ value of -12.0°/oo. This brackish-water value corresponds with the large amount of brackish ice found in the depression ice, and also with the brackish ice found at the bottom of the hummock ice (Figure 6). Thus, once deformation has occurred and the ice has consolidated, deformed MLSI also forms a stable environment for under-ice melt-pools.

The MLSI data indicate that there can be considerable variation in water properties at a given site, and also great variation between locations. The latter point also applies to Ward Hunt Ice Shelf, where under-ice water stratification is most likely related to the outflow of freshwater from behind a floating ice-dam.

Ice-Dams and Water Stratification

At the mouth of Disraeli Fiord, Ward Hunt Ice Shelf acts as a floating dam preventing the free exchange of fiord surface water with the Arctic Ocean. In consequence, a unique form of water stratification exists, with a 44 m deep freshwater layer (equivalent to the ice-shelf draft) overlying the deeper seawater (Keys 1978; Jeffries 1985). This phenomenon is illustrated conceptually in Figure 11.

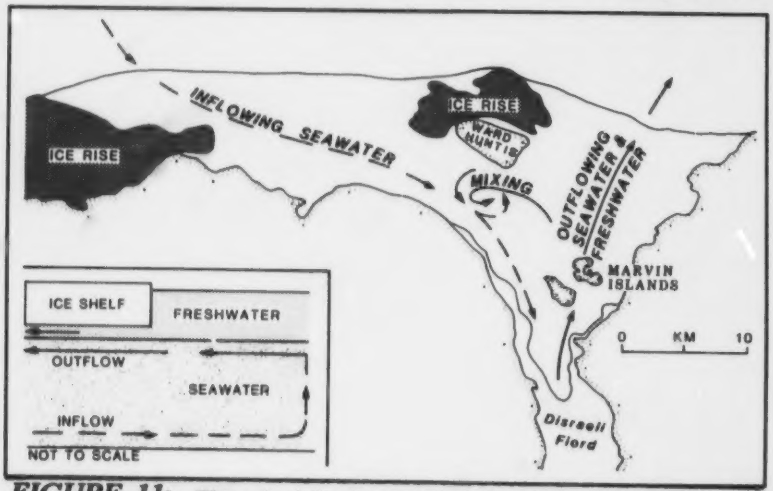


FIGURE 11: **Water circulation beneath Ward Hunt Ice Shelf inferred from ice core analysis (Jeffries et al. 1988A). The insert represents the ice-shelf dam and associated water stratification in Disraeli Fiord. (Reproduced by courtesy of the International Glaciological Society from Annals of Glaciology, Vol. 10, p. 72, Figure 6.)**

In Disraeli Fiord itself, platelet ice has been found to grow in supercooled water immediately above the halocline and then float upward to the surface of the fiord (Keys 1978). This was first observed in 1967, and the process was suggested as the means by which brackish ice grew at the bottom of the ice shelf (Lyons *et al.* 1971). For this to occur, freshwater or brackish water would have to flow out of Disraeli Fiord beneath the ice shelf. This is most likely to occur in the summer when meltwater runoff into the fiord is at a maximum.

The contrasting ice-core data for West and East Ward Hunt Ice Shelf is considered to be a proxy record of variations in water circulation and bottom freezing beneath the ice shelf (Jeffries *et al.* 1988A). The great thickness of sea ice in the West Ice Shelf is a record of sea-ice accretion associated with the flow of seawater below the ice shelf into Disraeli Fiord. Seawater flowing out of the fiord is directed below the East Ice Shelf; however, the East Ice Shelf is not underlain directly by a layer of seawater or brackish water, but by a layer of freshwater from the surface of Disraeli Fiord. The high level of tritium at the bottom of the ice indicates the recent flow of freshwater, with associated ice accretion.

Possibly, in the East Ice Shelf, ice growth resulting from the presence of this freshwater layer has been accompanied by surface ablation over a period of 450-500 years. As a result, freshwater ice has completely replaced any sea ice that originally grew to the east of Ward Hunt Island. This process of vertical ice migration is corroborated by the discovery of sponges and plant material, with radiocarbon dates of 400-450 years, at the ice surface adjacent to Ward Hunt Island (Crary 1960).

While the West and East Ice Shelf are underlain almost exclusively by seawater and freshwater respectively, there would appear to be variable mixing of inflowing seawater and outflowing freshwater ice in the region south of Ward Hunt Island. This would account for the variability of ice-types in this region, i.e., ice core 86-8 and "brackish basement ice" (Lyons *et al.* 1971).

The great thickness of sea ice in the West Ice Shelf and of freshwater in the East Ice Shelf suggest that the pattern of water circulation and ice accretion beneath the ice shelf has been quite consistent over a long period of time. However, Stratum 3 (Figure 10) in the West Ice Shelf suggests that water stratification and associated freshwater and brackish ice growth once occurred in this region. Jeffries and Krouse (1984) suggested that this occurred during an exceptionally warm climatic period when the volume of freshwater flowing into and out of Disraeli Fiord was far greater than today.

At Disraeli Fiord, Ward Hunt Ice Shelf lies across the entire mouth of the fiord and gives rise to a pronounced water stratification. At Ayles Fiord, Ayles Ice Shelf occupies about 75% of the fiord-mouth, with MLSI occupying the rest (Figure 2B). Conceivably, water-stratification also exists in Ayles Fiord but, rather than leaking out uniformly below the ice shelf, the low-salinity water tends to flow out beneath the MLSI. As in Disraeli Fiord, the flow of low-salinity water is likely seasonal, with a wedge of freshwater or brackish water penetrating far beneath the ice in summer, and retreating again in winter. In view of the apparently large amount of brackish ice in Ayles MLSI, there is probably greater mixing of freshwater and seawater so that the ice is underlain mostly by brackish water. In addition to the layer of low-salinity water flowing out uniformly below the MLSI in summer, probably pockets of it will persist in inverted depressions on the ice bottom. Thus, ice growth of Ayles Fiord MLSI might arise from a combination of influences, i.e., water-stratification associated with both under-ice melt-pools and floating ice-dams.

DISCUSSION AND CONCLUSION

We noted earlier that undeformed multi-year pack ice floes commonly have a steady-state thickness of 2.5-5.0 m (Maykut and Untersteiner 1971). Data presented here suggest that extensive areas of MLSI exceed this thickness, while the thickness of sea ice in West Ward Hunt Ice Shelf far exceeds any thick sea ice found to date. Thick sea-ice floes (>5 m) have been found occasionally in the Arctic Ocean (Walker and Wadhams 1979), and there appears to be little doubt that they were correct in suggesting that they originate at very high latitudes, e.g., the north coast of Ellesmere Island.

To account for thick sea-ice growth on thermodynamic grounds alone, Walker and Wadhams (1979) modified the Maykut and Untersteiner sea-ice growth model. With oceanic heat flux set to zero and annual snowfall at 1.0 m, an ice thickness of 12 m was reached in 65 years, and a thickness of 20 m after 200-300 years. This type of model might apply to the Nansen Ice Plug and West Ward Hunt Ice Shelf and account for the thick sea-ice growth there.

Thick sea-ice growth as described in the previous paragraph would be very slow. Possibly large areas of MLSI have grown quicker, in a manner independent of Maykut-Untersteiner-type ice-growth models (Jeffries and Krouse 1988). Data presented here suggest that water stratification is common below MLSI; hence MLSI growth can be accounted for by a double-diffusion process similar to that described by Martin and Kauffman (1974). In this case, the annual transfer of meltwater from the ice surface and surrounding land to a cold-sink below the ice will lead to thick sea-ice growth in a relatively short period of time. Jeffries and Krouse (1988) indicate a mean thickening-rate of 400 mm a^{-1}.

The growth of MLSI attached to thicker ice shelves raises the possibility that some MLSI growth might be associated with the operation of an "ice pump" (Lewis and Perkin 1983, 1986). Briefly, if sea water that has been in contact with an ice shelf at depth is raised, then as pressure reduces, it might become supercooled in relation to the in situ freezing point and could provide a heat-sink for ice growth within the water column. This has been observed in Antarctica, and it might occur off the north coast of Ellesmere Island.

The ice-pump principle is also relevant to the bottom topography of the ice. Lewis and Perkin (1983) describe the ice-pump as melting ice from a pressure ridge keel and depositing ice within a lead, with an overall tendency to produce a uniform ice thickness. They note that it is not necessary to have open water to start an ice pump of this type; any variation in ice thickness causing freezing-rate variations at the ice/water interface is sufficient. If applied to MLSI this would suggest a tendency toward a flat bottom-side on the ice. The ice-property data presented here suggests that this is not the case. Furthermore, Jeffries *et al.* (1988B) have observed that the entire thickness of hummock ice is colder than depression ice, and suggest that heat conduction through hummocks will be greater than through depressions. Thus, despite considerable ice growth by double-diffusion processes below depressions, greater ice growth will occur on hummock keels, and an undulating bottom topography will be maintained.

The foregoing discussion is necessarily speculative because studies of the heat and mass balance of MLSI, or of any other kind of thick sea ice are lacking. Field-data collection and subsequent modelling of the heat and mass balance of this thick ice would provide considerable insight into ice-growth processes below the ice - processes responsible for the thick sea-ice growth, and surface processes that are responsible for the initiation and perpetuation of the surface topography, and perhaps the bottom topography.

Studies of the physical properties of the ice, emphasizing stable-isotope tracing, indicate that such tracing can be usefully applied in sea-ice studies. In this case, it contributed to the disclosure that MLSI is often composed of brackish ice - an important discovery in its own right. It is also significant because there have been few studies of brackish ice anywhere. Hence, MLSI offers the opportunity to study not only the thermodynamics of thick brackish and sea ice, but also the physical and structural properties of this type of ice. With regard to the latter, Jeffries and Krouse (1988) suggested that structural characteristics in MLSI may govern the preservation of annual salinity layers. Indeed, 'brackish basement ice' in Ward Hunt Ice Shelf apparently has none of the platy substructure characteristic of sea ice (Lyons *et al.* 1971). Thus, brine-drainage is probably limited. MLSI represents an opportunity to examine these sorts of physical-structural characteristics.

ACKNOWLEDGEMENTS

The first author (M.O.J.) gratefully acknowledges the support of the following institutions: Department of Geography, University of Calgary, Polar Continental Shelf Project, Defence Research Establishment Pacific, Arctic Institute of North America, Gulf Canada, Dome Petroleum, Petro-Canada. The second author (H.R.K.) acknowledges Natural Sciences and Engineering Research Council of Canada funding of the stable-isotope laboratory at the University of Calgary. M.O.J. and W.M.S. thank the Geophysical Institute, University of Alaska (S.-I. Akasofu, Director) and the U.S. Department of Energy (Morgantown Energy Technology Center) for their continued support. We thank: G. Holdsworth for help with drilling ice core 83-1; Dave Terroux (Surveys and Mapping, Energy, Mines and Resources Canada) for operating the aerial camera in 1984; and the P.U.N.S. Expedition (1985-1986) to Ward Hunt Ice Shelf (leader, Sir Ranulph Fiennes) for drilling ice core 86-8. We also thank the Resolute Bay weather station (AES Canada) for allowing us to store the ice cores in one of their freezers.

REFERENCES

Craig, H. 1961. Standard for reporting concentrations of deuterium and oxygen-18 in natural waters. Science 133:1833-1834.

Crary, A.P. 1958. Arctic ice island and ice shelf studies, Part I. Arctic 11:2-42.

______. 1960. Arctic ice islands and ice shelf studies, Part II. Arctic 13:32-50.

Hanson, A.N. 1965. Studies of the mass budget of arctic pack-ice floes. Journal of Glaciology 5:701-709.

Hattersley-Smith, G. 1957. The rolls of the Ellesmere Ice Shelf. Arctic 10:32-44.

Hattersley-Smith, G., A. Fuzesy, and S. Evans. 1969. Glacier depths in northern Ellesmere Island: airborne radio echo sounding in 1966. Operation Tanquary, DREO Technical Note 69-6, Geophysics Hazen 36. Defence Research Board, Department of National Defence, Ottawa.

Jeffries, M.O. 1985. Physical chemical and isotopic investigations of Ward Hunt Ice Shelf and Milne Ice Shelf, Ellesmere Island, N.W.T. Ph.D. thesis, University of Calgary, Calgary, Alberta.

______. 1986. Glaciers and the morphology and structure of Milne Ice Shelf, Ellesmere Island, N.W.T., Canada. Arctic and Alpine Research 18:397-405.

Jeffries, M.O. and H.R. Krouse. 1984. Arctic ice shelf growth, fiord oceanography and climate. Zeitschrift für Gletscherkunde und Glazialgeologie 20:147-153.

______. 1987. Snowfall and oxygen isotope variations off the north coast of Ellesmere Island, N.W.T., Canada. Journal of Glaciology 33:195-199.

______. 1988. Salinity and isotope analysis of some multiyear landfast sea ice cores, northern Ellesmere Island, Canada. Annals of Glaciology 10:63-67.

Jeffries, M.O. and H. Serson. 1983. Recent changes at the front of Ward Hunt Ice Shelf, Ellesmere Island, N.W.T. Arctic 36:289-290.

______. 1986. Survey and mapping of recent ice shelf changes and landfast sea ice growth along the north coast of Ellesmere Island, N.W.T., Canada. Annals of Glaciology 8:96-99.

Jeffries, M.O., W.M. Sackinger, and H.V. Serson. 1987. Remote sensing of sea ice growth and melt-pool evolution, Milne Ice Shelf, Ellesmere Island, Canada. Annals of Glaciology 9:145-150.

Jeffries, M.O., W.M. Sackinger, H.R.Krouse, and H.V. Serson. 1988A. Water circulation and ice accretion below Ward Hunt Ice Shelf (northern Ellesmere Island, Canada), deduced from salinity and isotope analysis of ice cores. Annals of Glaciology 10:68-72.

Jeffries, M.O., W.M. Sackinger, and H.D. Shoemaker. 1988B. Some physical properties of multiyear landfast sea ice, northern Ellesmere Island, Canada. In: Port and Ocean Engineering under Arctic Conditions. Edited by: W.M. Sackinger and M.O. Jeffries. Geophysical Institute, University of Alaska. pp. 57-68.

Keys, J.E. 1978. Water regime of Disraeli Fiord, Ellesmere Island. DREO Report No. 792. Research and Development Branch, Defence Research Establishment, Ottawa, DND, Ottawa.

Koenig, L.S., K.R. Greenaway, M. Dunbar, and G. Hattersley-Smith. 1952. Arctic ice islands. Arctic 5:67-103.

Lewis, E.L. and R.G. Perkin. 1983. Supercooling and energy exchange near the Arctic Ocean surface. Journal of Geophysical Research 88:7681-7685.

______. 1986. Ice pumps and their rates. Journal of Geophysical Research 91:11,756-11,762.

Lister, H. 1962. Heat and mass balance at the surface of the Ward Hunt Ice Shelf. Arctic Institute of North America, Research Paper No. 19.

Lyons, J.B. and F.G. Leavitt. 1961. Structural-stratigraphic studies on the Ward Hunt Ice Shelf. Report No. AFCRL-442, USAF Cambridge Research Laboratory, Geophysical Research Directorate, Bedford, Massachusetts.

Lyons, J.B. and R.H. Ragle. 1962. Thermal history and growth of the Ward Hunt Ice Shelf. Union Géodésique et Géophysique International, Association International des Sciences Hydrologiques. Commission des Neiges et Glaces, Colloque d'Obergurgl (September 10-18, 1962). pp. 88-97.

Lyons, J.B, S.M. Savin, and A.J. Tamburi. 1971. Basement ice, Ward Hunt Ice Shelf, Ellesmere Island, Canada. Journal of Glaciology 10:93-100.

Martin, S. and P. Kauffman. 1974. The evolution of under-ice melt ponds, or double diffusion at the freezing point. Journal of Fluid Mechanics 64:507-527.

Mason, B. and C.B. Moore. 1982. Principles of geochemistry. Fourth Edition, John Wiley and Sons Inc., New York. 344 pp.

Maykut, G.A. and N. Untersteiner. 1971. Some results from a time-dependent thermodynamic model of sea ice. Journal of Geophysical Research 76:1550-1575.

Narod, B.B., G.K.C. Clarke, and B.T. Prager. (in press). Airborne UHF radar sounding of glaciers and ice shelves, northern Ellesmere Island, Canada. Canadian Journal of Earth Sciences.

Ommanney, C.S.L. 1982A. Bibliography of Canadian glaciology, 1982-Bibliography No. 2/Ellesmere Island Glacier and Ice Shelves. National Hydrology Research Institute, Environment Canada, NHRI Report No. 20.

______. 1982B. Bibliography of Canadian glaciology, 1982-Bibliography No. 3/Ice Islands of the Arctic Ocean. National Hydrology Research Institute, Environment Canada, NHRI Report No. 21.

O'Neil, J.R. 1968. Hydrogen and oxygen isotope fractionation between ice and water. Journal of Physical Chemistry 72:3683-3684.

Östlund, H.G. and G. Hut. 1984. Arctic Ocean water mass balance from isotope data. Journal of Geophysical Research 89:6373-6381.

Ragle, R.H., R.G. Blair, and L.E. Persson. 1964. Ice core studies of Ward Hunt Ice Shelf. Journal of Glaciology 5:39-59.

Serson, H.V. 1972. Investigation of a plug of multi-year old sea ice in the mouth of Nansen Sound. Defence Research Establishment, Ottawa, Technical Note 72-6.

Untersteiner, N. and F.I. Badgley. 1958. Preliminary results of thermal budget studies on Arctic pack ice during summer and autumn. In: Arctic Sea Ice. U.S. National Academy of Sciences - National Research Council, Publication No. 598:85-98.

Vetshteyn, V.Y., G.A. Malynk, and V.P. Rusanov. 1974. Oxygen-18 distribution in the central Arctic Basin. Oceanology 14:514-519.

Walker, E.R. and P. Wadhams. 1979. Thick sea ice floes. Arctic 32:140-147.

Weeks, W.F. and S.F. Ackley. 1982. The growth, structure and properties of sea ice. CRREL Monograph 82-1.

Illustrated by Brenda Carter

ACOUSTIC RESEARCH IN THE CANADIAN ARCTIC: SOUNDING THROUGH SEA ICE AND ICEBERG DETECTION

Phillipe de Heering[1]

Abstract: The paper presents photographic documents illustrating two acoustic research projects recently completed in the Canadian Arctic Islands: non-contact through-the-ice sounding and iceberg sonar-detection. A brief description of the goals and results of these projects is provided.

Résumé: On présente des documents photographiques relatifs à deux projets de recherches récents ayant trait à l'Arctique canadien: le télésoundage des mers arctiques et la détection sonar d'icebergs. On fournit également une brève description des buts et résultats desdits projets.

INTRODUCTION

During the last few years, several acoustic research projects have been carried out in the Canadian Arctic for both commercial and military applications. While the military work results directly from an increased perception of the strategic importance of this part of the world, the commercial aspects of the research are more diversified, and include geophysics, hydrography and the sonar-detection of ice-hazards from ships navigating the region.

I provide briefly here a photographic description of selected aspects of two such projects that I and my colleagues have completed. The scientific results of this work have been discussed elsewhere (De Heering 1987; De Heering and Sutcliffe 1987) and will be merely outlined below.

SOUNDING THROUGH SEA ICE

The first program, "Non-Contact Through-The-Ice-Sounding", carried out for the Canadian Hydrographic Service (Fisheries and Oceans Canada), dealt with the development of an acoustic approach to airborne sounding of arctic waters. This effort was motivated by the fact that the sounding of Canadian Arctic waters presents the special problem that these

---

[1] Canadian Astronautics Limited, 1050 Morrison Drive, Ottawa, Ontario K2H 8K7

waters - which are covered in many areas by ice throughout much of the year - are not readily accessible to hydrographic ships. For this reason, Fisheries and Oceans Canada is actively pursuing research and development related to sounding under these special conditions.

For example, current over-ice hydrographic surveys are carried out from a helicopter (Bell 206-B) that bears a special echo-sounding device. To take one sounding, the helicopter first lands, then an electro-acoustic transducer carried by a mechanical ram outside the helicopter is applied against the (often snow-covered) ice. The system then measures the delay between the transmission of an acoustic impulse and the reception of an echo, which is a measure of the water-depth. This, and similar systems feature relatively slow mapping-rates, as the vehicle needs to stop at each sounding point.

To circumvent this problem, an alternative approach aiming at non-contact sounding from a helicopter in flight was developed and tested. This technique, (Figure 1) involves the transmission of an acoustic sounding impulse in the water resulting from the impact on the ice of a high-speed bullet shot from the helicopter. The pulse reflected by the seafloor is received by a specially designed microphone system flown above the ice. The water-depth can be deduced from the echo-delay and other relevant parameters.

The field work was carried out from two locations in the Canadian Arctic Islands: the first phase during April 1984 near Browne Island; and the second on Intrepid Bay, Cornwallis Island. Figure 2 shows our camp on the sea ice established in April for preliminary tests of the sounding concepts. The photograph is taken from a 7.6 m high platform for shooting at the ice in the bullet-impact acoustic measurements. The bullet-impact sounds were received by hydrophones suspended through the ice in the water, then recorded and analyzed (Figure 3). Figure 4 illustrates the method used to acoustically-decouple from the ice a microphone used for airborne reception of the seafloor echoes. The prototype transmission and receiving devices were mounted on a helicopter (Figures 5, 6). The former consists of a .30 calibre Weatherby gun mounted on the right side of the helicopter, whereas the latter is a "bird" suspended from the helicopter and instrumented with two microphones and an altimeter. The received echoes were recorded on board the helicopter and analyzed on the site and in Ottawa.

Very encouraging results have been obtained, but more work is needed to demonstrate the feasibility of the approach.

ICEBERG DETECTION

The second program dealt with shipborne sonar detection (Figure 7) of icebergs in ice-free and ice-covered arctic waters. The field trials were carried out in the Lancaster Sound-Baffin Bay area from the icebreaker M.V. *Arctic* (owned by Canarctic Shipping Company Limited). The usefulness of sonar iceberg-detection results from the fact that the propagation path of underwater sound is distinct from that of the propagation path for electromagnetic radar signals, so that fades of the two systems are expected to be statistically independent. Thus, sonar and radar combined detection statistics would be significantly more favourable than those of each of the sensors alone, in their range of overlap. Note too that some 90% of the iceberg-mass is underwater, thereby providing a larger target-area for waterborne signals than for airborne signals. Also, in the short range, radar may suffer reduced performance due to unfavourable geometry, while the sonar ordinarily does not.

Furthermore, visual detection of icebergs (Figure 8) is often made difficult by the polar night or by fog (Figure 9), whereas the ice-cover often contributes radar clutter which is difficult to distinguish from echoes of small bergs. In the course of summer field work in 1984 and 1986, during the passage between Nanisivik on northern Baffin Island and Antwerp, Belgium, iceberg acoustic-echo data were obtained by means of a modified fish-finding sonar made by C-Tech, Cornwall (Figure 10) and operated together with a specially-configured data-acquisition system (Figure 11).

Data-acquisition and analysis trials demonstrate the acoustic feasibility of sonar detection of icebergs from a ship at ranges of 50-2,000+ m. In addition, the in situ acoustic cross-section (or target-strength) measurements, together with the acoustic environment measurements, which were undertaken during the tests, provide a realistic basis for the design of an active sonar dedicated to iceberg detection.

ACKNOWLEDGEMENTS

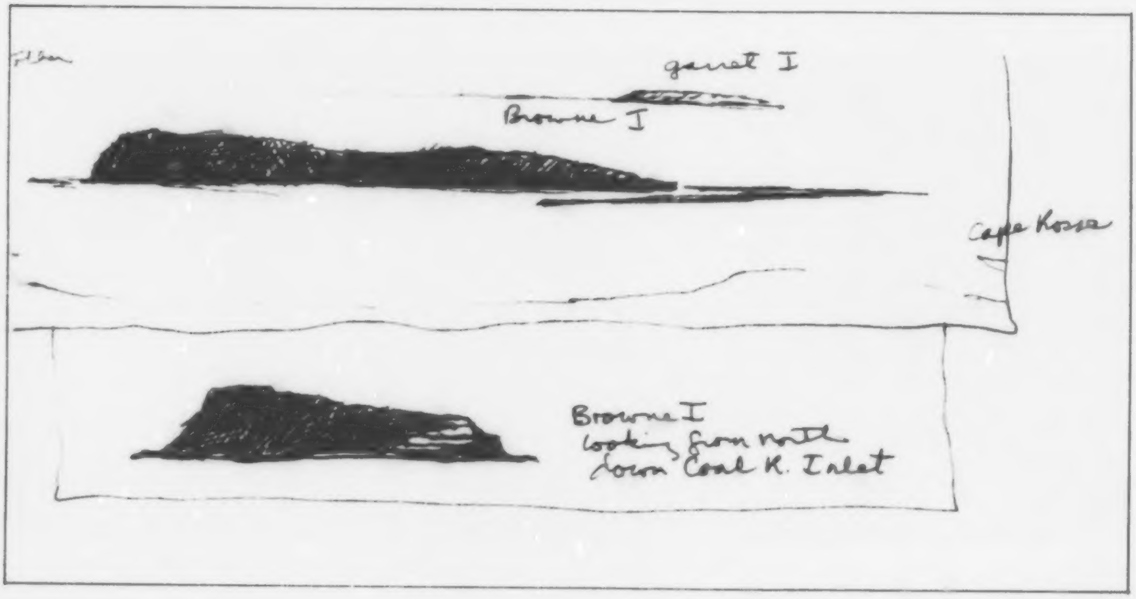
Logistical support for trials during the first program was made possible by the Polar Continental Shelf Project (Energy, Mines and Resources Canada) in Resolute. Without their

support, the field work discussed here would not have been carried out. Canarctic Shipping Company Limited of Ottawa and Transport Canada supported the second program.

REFERENCES

De Heering, Phillipe. 1987. Acoustic measurements and applications of kinetic impacts on ice. In: Progress in Underwater Acoustics. Edited by: H.M. Merklinger. Plenum, New York. pp. 611-618.

De Heering, Phillipe, and P. Sutcliffe. 1987. Active sonar detection of icebergs. In: Proceedings 11-e colloque sur le traitement du signal et ses applications (June 1987, Nice, France). pp. 333-336.



garret I
Browne I
Cape Kossa
Browne I
looking from north
down Coal K. Inlet

Illustrated by Brenda Carter

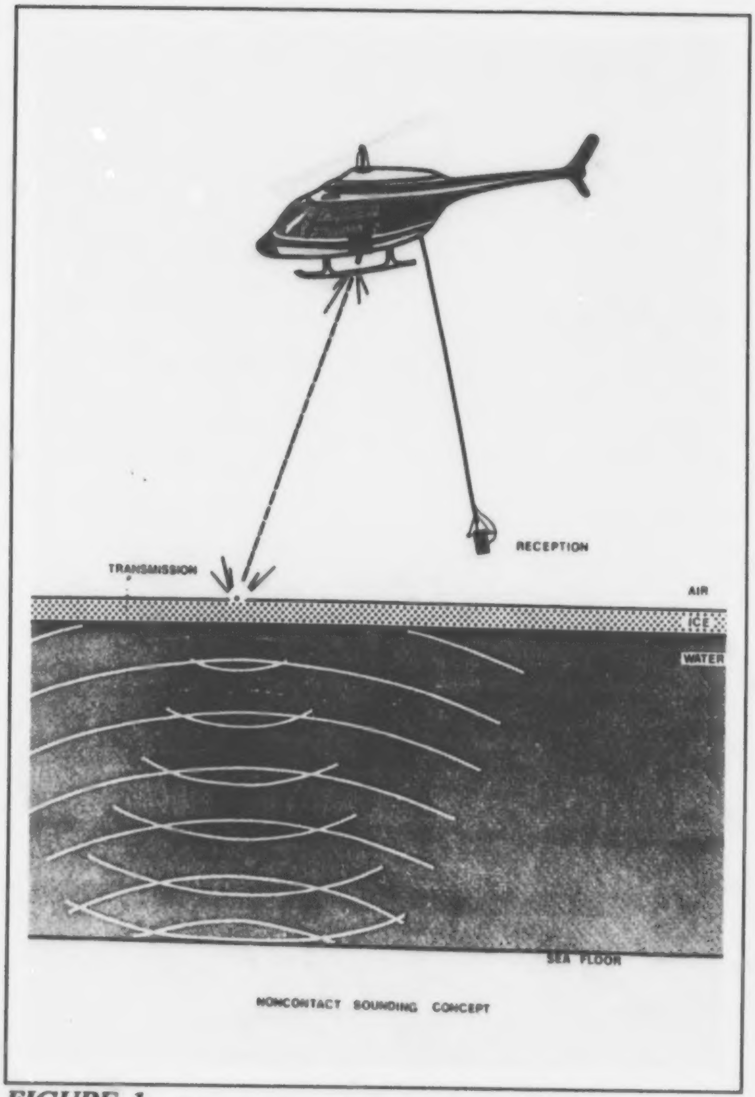

RECEPTION
TRANSMISSION
AIR
ICE
WATER
SEA FLOOR
NONCONTACT SOUNDING CONCEPT

FIGURE 1: Non-contact sounding concept using a helicopter.

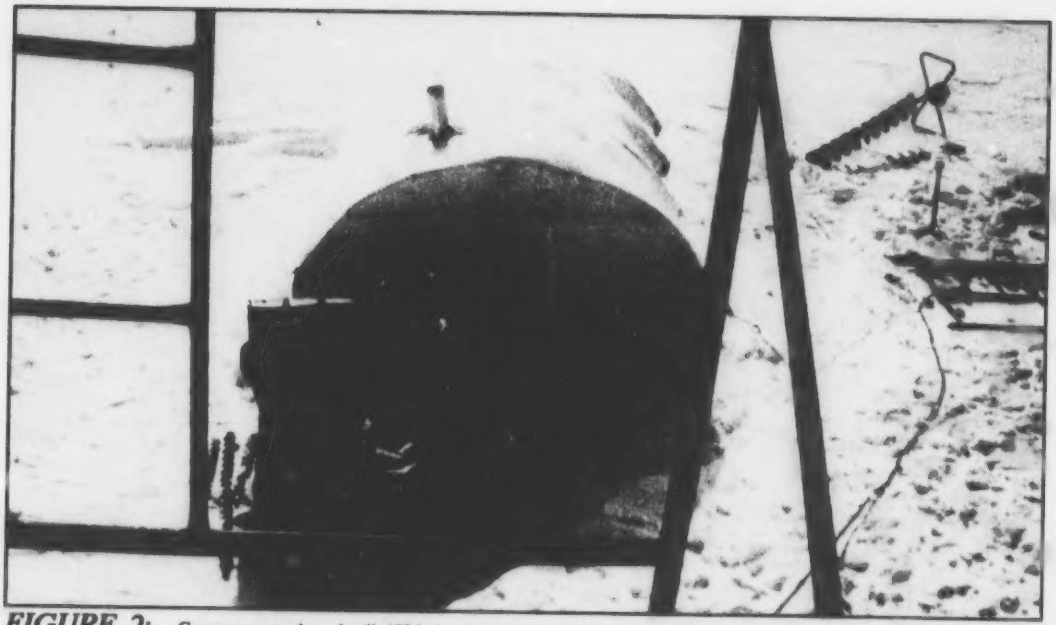


FIGURE 2: Camp on sea ice, April 1984, in the vicinity of Browne Island, southwest of Resolute Bay.

FIGURE 3: Facilities (shelter and stove) in the Camp made available by the Polar Continental Shelf Project resulted in a comfortable environment.

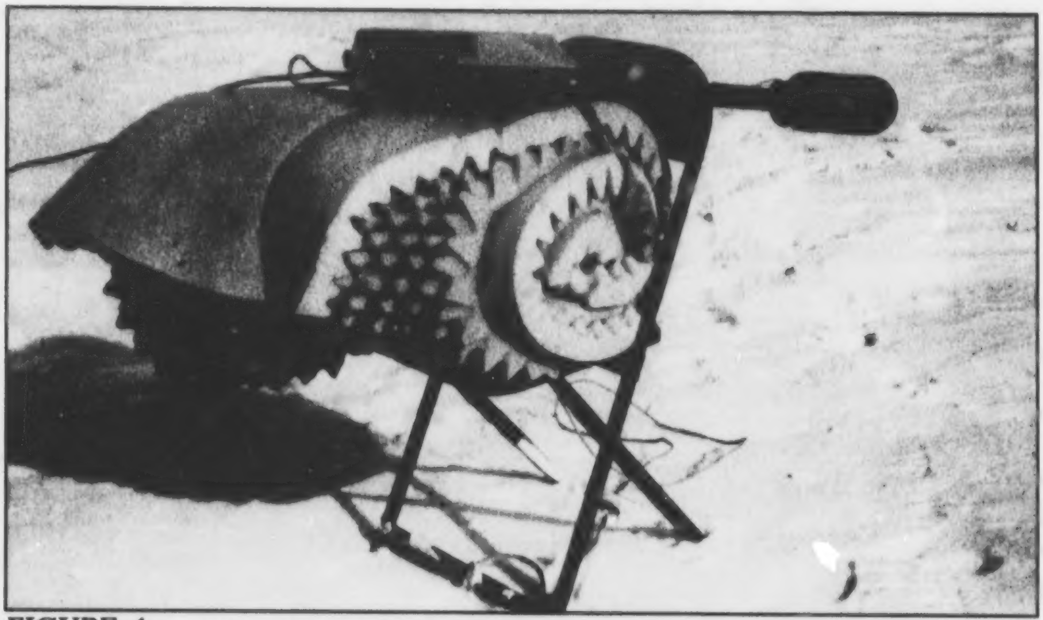


FIGURE 4: Receiving microphone above the sea ice.

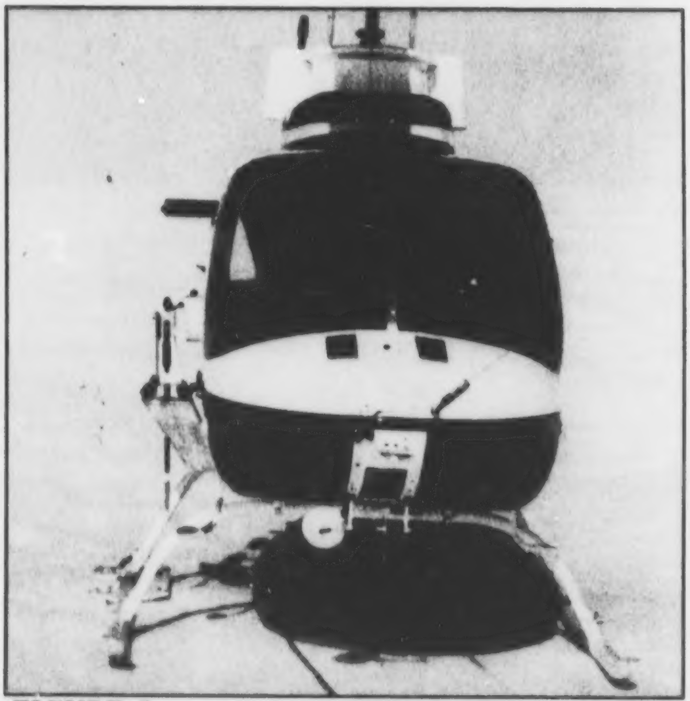


FIGURE 5: Prototype - transmitting system. Rifle attached to helicopter.

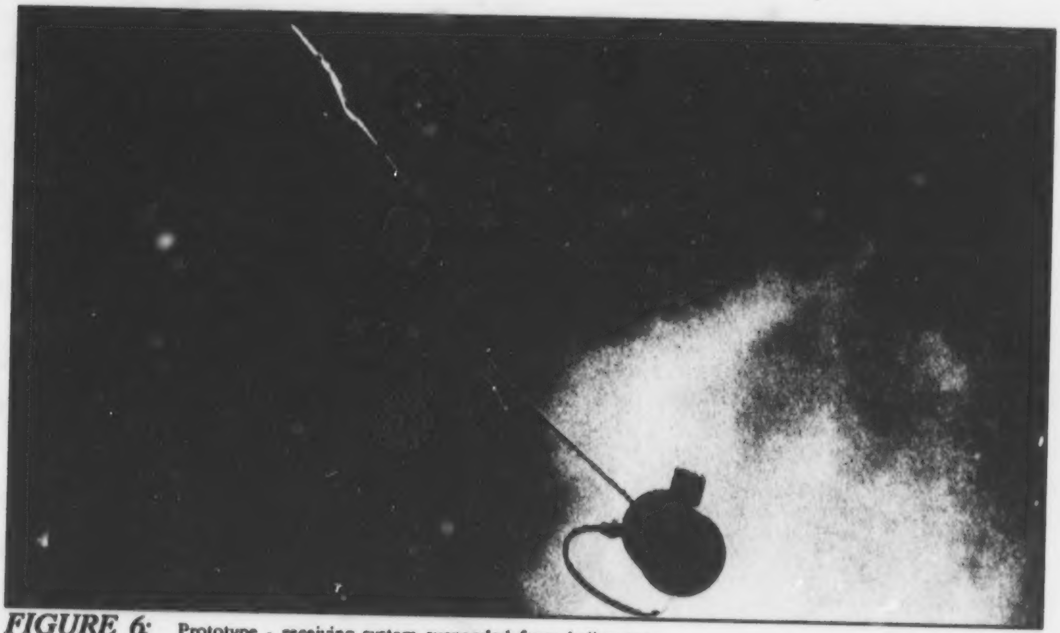


FIGURE 6: Prototype - receiving system suspended from helicopter.

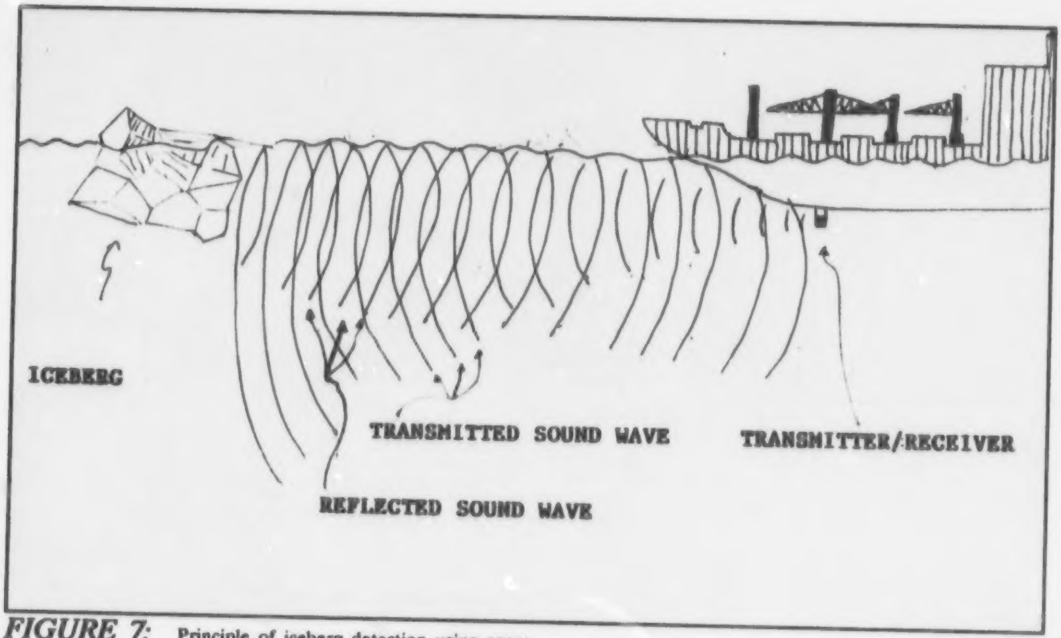

ICEBERG
TRANSMITTED SOUND WAVE
TRANSMITTER/RECEIVER
REFLECTED SOUND WAVE

FIGURE 7: Principle of iceberg detection using sonar.

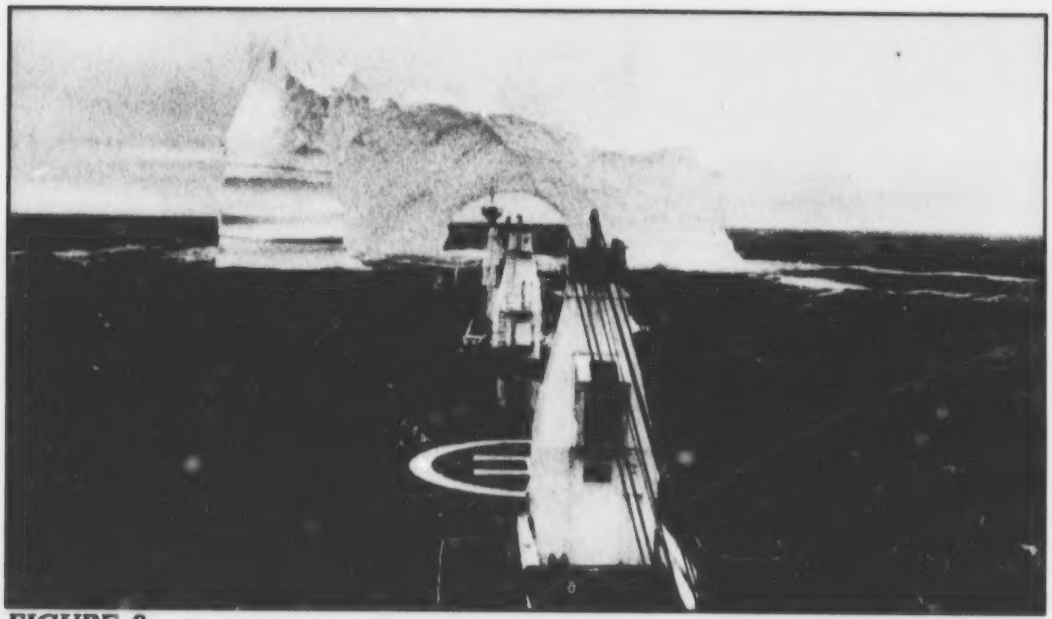


FIGURE 8: Grounded iceberg off bow of M.V. Arctic.

FIGURE 9: Testing during foggy conditions.

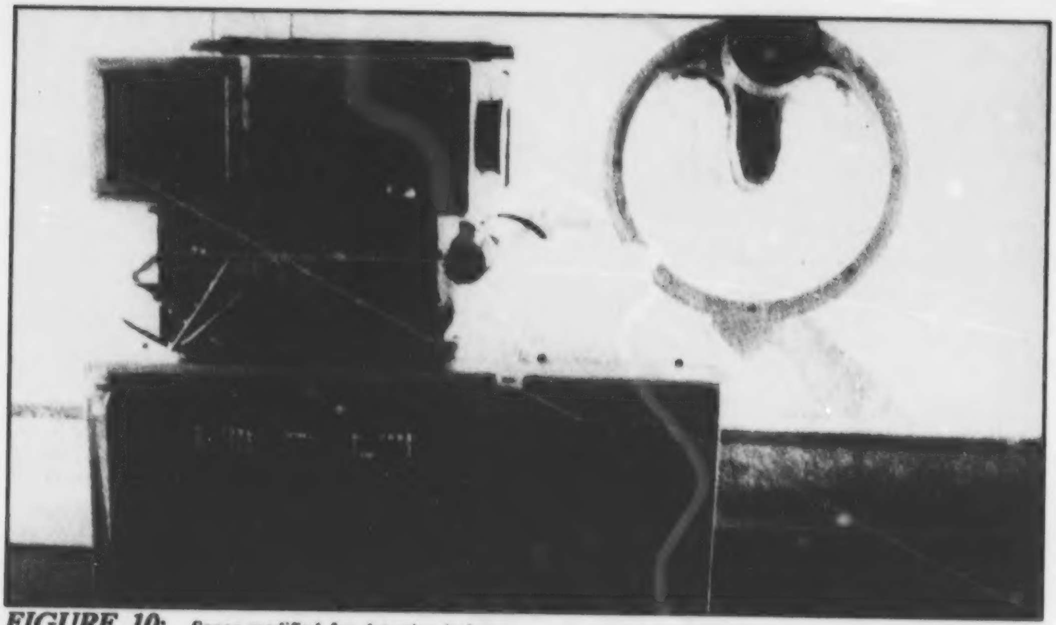


FIGURE 10: Sonar modified for detecting icebergs.

FIGURE 11: Data-acquisition systems aboard M.V. Arctic operated in combination with the sonar.

ARCTIC ICE CORES: PUTTING PRESENT CLIMATE INTO PERSPECTIVE

Roy M. Koerner[1]

Abstract: Our present climate is far from normal when viewed in terms of the past 100,000 years of record. Data are based on oxygen-isotope ratios or "delta-values" for ice-core samples from various levels in a core from the Agassiz Ice Cap on northeastern Ellesmere Island. The Agassiz data indicate that: (1) climate there has been colder then present for about 80,000 of the past 100,000 years; (2) ice caps in the Arctic Islands melted completely during the last interglacial; and (3) the climate of the last 60 years has been colder than average for the last 10,000 years, but warmer than average for the last 1,000 years.

Although global circulation models predict that greenhouse gases (e.g. carbon dioxide) will cause a warming of several degrees Celsius in the High Arctic during the next century, presumably this warming would not persist long enough to completely melt Canadian Arctic Islands ice caps. Perhaps the early phase of the last interglacial may be the best analogue for such warmer conditions.

Résumé: Le climat actuel est loin d'être normal si on le considère à la lumière des 100,000 dernières années. Les données sont basées sur les rapports d'isotopes de l'oxygène ou "valeurs delta" pour des échantillons pris à différents niveaux sur une carotte de glace provenant de la calotte glaciaire d'Agassiz, sur le nord-est de l'île Ellesmere. Les données d'Agassiz montrent que: (1) le climat y a été plus froid qu'actuellement pendant environ 80,000 des 100,000 dernières années, (2) les calottes glaciaires dans les îles de l'Arctique ont fondu complètement au cours du dernier interglaciaire, (3) le climat des 60 dernières années a été plus froid que la moyenne des 10,000 dernières années, mais plus chaud de la moyenne des 1000 dernières années.

Bien que les modèles de circulation globale prévoient que les gaz à effet de serre (par ex., le gaz carbonique) entraîneront un réchauffement de plusieurs degrés Celsius dans le Haut-Arctique au cours du prochain siècle, ce réchauffement ne persistera probablement pas assez longtemps pour faire fondre totalement les calottes glaciaires des îles de l'Arctique canadien. La première phase du dernier interglaciaire constitue peut-être la meilleure analogie de ces conditions plus chaudes.

INTRODUCTION

Glaciers and ice sheets throughout the world are strongly related to climate. In the past, during periods of intense cold, ice masses have expanded to cover large parts of North America and Europe. Mountain glaciers have also expanded during these times, and it appears from the ocean record that over the past million years the more normal condition is for much colder conditions than today, with ice sheets covering large parts of Canada. However, these are the most dramatic changes, and it must be realized that climate changes through a wide range of wavelengths and amplitudes, from millennial to decadal and from fractions of a degree to several degrees. Ice sheets contain records of all these changes.

---

[1] Terrain Sciences Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8
Geological Survey of Canada Contribution No. 44988

ICE CAPS AND GLACIERS

An ice or snowfield becomes "permanent" once it is able to survive each summer. To do this, the snowfalls of winter must exceed the ice-melt of summer. Snow survives at high elevations but melts, along with some of the underlying ice, in the lowermost regions. In the more dynamic ice caps - those with outlet glaciers reaching the sea - some ice may break off and melt in the ocean.

Ice formed in the accumulation area moves down toward the underlying rock as it is buried under subsequent snowfalls. It also moves out toward the margin. The ice in the ablation zone also moves toward the margin, but its vertical component is upward, replacing the ice that melts. The thickness of the annual snow-layer at the surface varies from about 1.5 m close to Baffin Bay to as little as 0.15 m on parts of the more northerly ice caps on Ellesmere and Axel Heiberg islands. In the ablation zone, between 1 m and 3 m of ice melts at sea level each summer. The equilibrium line (where snow accumulation equals snow melt) varies in elevation from 900 m to 1300 m above sea level in the Canadian Arctic Islands.

ICE CORES

Because the vertical component is almost entirely downward at the top of an ice cap, cores for climate studies are best taken there, as they suffer minimal disturbance by flow over irregular bedrock. Such cores contain records of snowfall beginning with the time the ice cap began its growth and extending to the present day. Everything that falls with the snow, including dust, pollen, and soluble salts is gradually buried. Several surface-to-bedrock cores, spanning a time interval of about 100,000 years over a depth increment of 100 m to 300 m, have been drilled in the Arctic Islands.

As it is buried by subsequent snowfalls the surface annual-layer thins by compression under increasing thicknesses of overlying snow until it becomes ice at a depth of about 60 m. At greater depths the layer continues to thin due to ice movement. In an ice cap 150 m thick, an annual-layer at 135 m is about 10,000 years old and less than 1 mm thick. Thus a core cannot be dated by simply dividing the core length by the surface annual-layer thickness. Instead, time-scales are determined by detecting seasonal swings in the concentration of micro-particles or ions in the ice, and by picking up high levels of acidity in the cores attributable to well-known, dated volcanic eruptions. These two methods date the ice back to about 7,000 years. Beyond that, the time-scale becomes increasingly inaccurate. We can only get an approximate date for any particular level by comparison with the better-dated Camp Century core in Greenland (Dansgaard *et al.* 1982) or with the fairly well-dated ocean cores (Hammer *et al.* 1980).

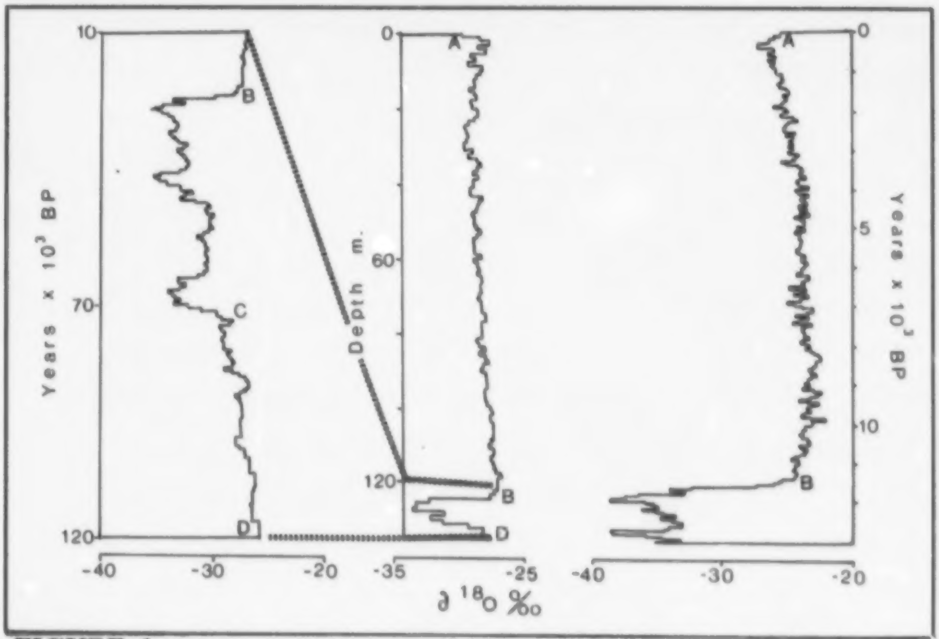


FIGURE 1: Oxygen isotope values for a core from the top of Agassiz Ice Cap (Ellesmere Island) drilled in 1979. The figure is in three sections. The middle section shows delta-values on a linear depth-scale from the snow surface to the bed underneath. The very cold values just below 'B' represent ice deposited during the last (Wisconsin) glacial period when the Laurentide Ice Sheet covered most of Canada.

The section on the left is a magnified version of the lowermost part of the ice and is again plotted on a linear depth-scale. Approximate ages of the ice are shown on the vertical axis. 'B' to 'C' represents the last glacial period and 'C' to 'D' (the bed) represents part of the last (Sangamon) interglacial period.

The section on the right is a linear time-scale plot of the delta-values of ice deposited during the last 12,000 years. The 'A' to 'B' section consists of ice deposited during the present interglacial period (Holocene). Note it shows a general cooling which persisted to within a hundred years of the present. Present conditions (the last 50 yrs) are shown as cooler than the greater part of the past 10,000 years.

Perhaps the most important climatic indicator in the ice cores is the *oxygen isotope ratio* or "delta-value". The more negative the delta-value, the lower the temperature the snow formed at. Figure 1 shows a delta-value profile for a core from the Agassiz Ice Cap on northeastern Ellesmere Island. The core is from the top of the ice cap at an elevation of 1,702 m above sea level.

The profile can be broken into three major sections: (1) an uppermost section (0-122 m) with "warm" delta-values; (2) an intermediate section (122-128 m) with very "cold" delta-values; and (3) a lowermost section (128 m to bed) where the delta-values gradually increase toward the bed. The uppermost section was deposited during the Holocene period (the last 10,000 years). The intermediate section represents the coldest period of the last (Wisconsin) glaciation from 10,000 to 70,000 years ago. The temperatures during this period were several degrees colder than today. The lowermost section was deposited during the last (Sangamon) interglacial period in warmer conditions than today but also during the cooling transition period that brought the Wisconsin glaciation. When the delta-profile is examined in more detail, the values suggest that, once the ice cap began its growth, the air temperature above gradually cooled toward the peak of the last glaciation. It appears that the ice cap started its growth sometime during the last interglacial. Any ice cap from the previous glacial period must have melted completely during the last interglacial. Other evidence in the core (e.g. pollen concentrations and the texture of the ice itself) supports this interpretation. The most recent 10,000-year section of core shows a period of maximum warmth closely following the dramatic emergence from glacial conditions. The climate has been cooling ever since.

A few important points about these profiles from the Arctic Islands are relevant to today's debate about the direction in which climate may be heading: (1) The climate at the drill-site has been colder than today's for about 80,000 of the past 100,000 years. We tend to view our current climate as "normal"; however, it is far from normal when viewed in terms of 100,000 years of record. Using ocean-core records we might even say the planet's climate is due to return to the "normal" condition of an ice age. What we should be seeking is not the cause of ice ages but the cause of interglacial periods. (2) If ice caps in the Canadian Arctic Islands melted completely during the main part of the last interglacial then that period must have been substantially warmer and/or longer than the present one. (3) The climate of the last 60 years has been colder than average for the last 10,000 years but warmer than average for the last 1,000 years.

Our view of present climate depends very much on our terms of reference. Predicting climate is often considered, particularly by the layperson or politician, as the end-product of paleoclimatic research. So a common question is: "What is the climate going to do in the future?" One has to have some kind of answer ready, and it should be based on a long time-series of high-quality proxy climate data. In our case, delta-value has been used, as it can be reproduced by adding two to four sine waves of different period, amplitude, and phase. Extrapolation can then be made by adding this sine-wave sum or synthesis. The calculations suggest a slight average annual cooling over the next 50 years of about 0.5°C to 1.0°C. Summer cooling in the next 50 years (based on the amount of melting as evidenced by clear ice-layers in the cores) may be slightly more than this. Although the standard error of this forecast is of similar magnitude to the change itself, other calculations based on delta-values from Greenland cores give similar "forecasts" to ours. Anthropogenic effects apart, we should not expect the open sea-ice conditions of the 1940s and the 1950s to occur again. Perhaps we should plan for the most pessimistic side of climate in the Arctic Islands and take the coldest summers from the past 40 years of record as a practical norm.

Computer models suggest that industrial atmospheric pollutants are going to profoundly affect our climate, if not in our lifetime, at least in that of our children. Just over a decade ago it was suggested that industrial pollutants could cause a premature slide into the next ice age; this was the "human volcano" hypothesis. Starting with the premise that volcanic activity causes global cooling, it was argued that dust from industrial activity would have a similar but persistently increasing effect. Our cores contain evidence of volcanic activity, mainly from eruptions in Alaska, Yukon, and Iceland. The eruptions appear as high levels of acidity in the cores. We have been unable, up to now, to demonstrate either a cooling or warming effect of volcanic activity by relating the high acid-levels to changing oxygen-isotope values in the cores. However, Hammer *et al.* (1980) concluded from work on Greenland cores that high acid-background levels in the ice are associated with slightly "colder" delta-values. In other words, climate may change in response to persistent, rather than peak, levels of volcanic activity maintained over many years.

The "human volcano" hypothesis has now been superseded by that of the effect of increasing levels of "greenhouse" gases, particularly carbon dioxide. Global circulation models predict dramatic warming over the next 100 years, particularly in the High Arctic (see McKay, this volume). Ice cores have played their part here also. Greenland cores have shown lower levels of carbon dioxide in ice deposited during the last glacial period. However, this is a chicken-and-egg problem. Do the carbon dioxide changes precede or follow the delta-value changes? Are they a cause or an effect?

CLIMATE MONITORING

Our cores have not yet been analyzed for carbon-dioxide concentrations. However, the Arctic Island ice caps are being used in another way for climatic research: to determine the way climate is heading. Each summer, melting occurs on the ice caps. At sea level, 2 to 3 m of ice may melt and run off onto the surrounding land or into the sea. Melting even occurs at the tops of the ice caps in most years, although it may be for only a few days. Each spring on the Melville South, Meighen, Devon, and Agassiz ice caps, measurements are made of the amount of ice and snow that melted the previous summer and the amount of snow remaining from the previous "year", ending with the last melt of summer. This gives a time-series of ice-melt and snow accumulation for a "balance-year" beginning one August and ending the next. The Meighen and Devon ice cap records now cover 27 years. No significant trends of changing snow accumulation or ice-melt rates can be found in the data, although large year-to-year variations may be burying any slight trend that does exist.

DISCUSSION

The ice-core record (Figure 1) shows a large range of climatic conditions over the past 100,000 years. Compared to the last 10 years, temperatures show a range from about 10°C to 15°C colder 18,000 years ago through 3°C warmer 7,000 to 8,000 years ago, to 5°C warmer more than 100,000 years ago when the ice cap began its growth. On a shorter time-scale, during the period of instrumental record, there is evidence from our cores of a 2.5°C warming between about 1750 and 1950. The warming trend, which has occasionally been identified as carbon-dioxide induced, can be seen as part of a much longer natural one.

Although global circulation models all predict that greenhouse gases will eventually cause a warming of several °C in the High Arctic, the amount of warming varies from model to model. However, the ice-core record suggests that the last interglacial, which may have seen the demise of all Canadian ice caps, may be used to represent an environment in which the level of carbon dioxide is doubled. Various studies of the paleoenvironment from that period can provide valuable input into estimating the effects of the proposed warming. Data of this nature are already available, much of it within the Quaternary Environments subdivision of the Geological Survey of Canada. However, it must be pointed out that "greenhouse warming" would not persist long enough to completely melt the ice-caps in the Canadian Arctic Islands. The closest scenario of a carbon-dioxide world might, therefore, be the early part of the last interglacial period when the High Arctic ice caps had still not melted completely.

ACKNOWLEDGEMENTS

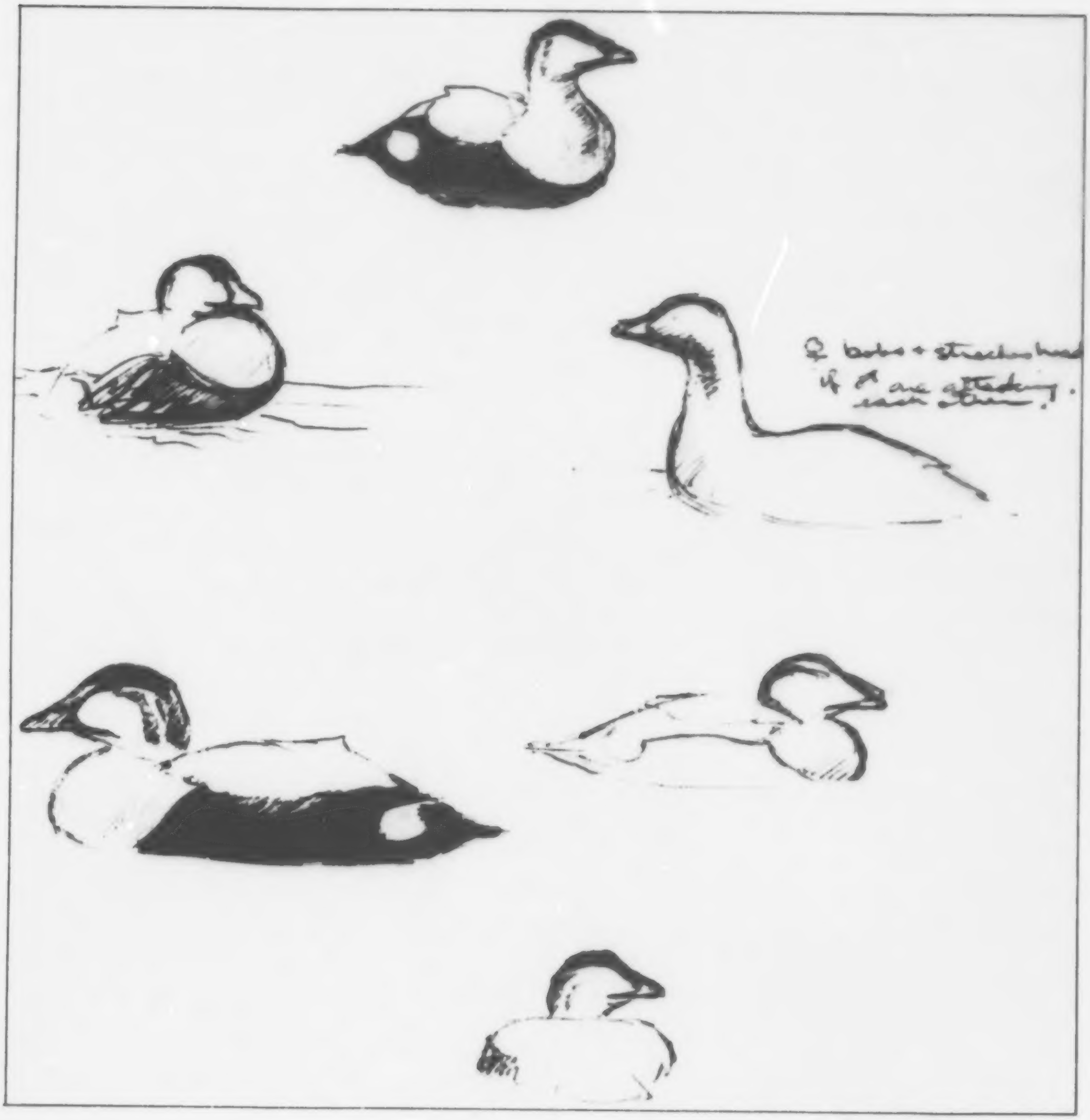
I am grateful to John Merritt (Executive Director, Canadian Arctic Resources Committee) and Alan Saunders (Editor, Northern Perspectives) for allowing me to publish a revised version of a paper first published in Northern Perspectives 15(5):10-12, 1987.

REFERENCES

Dansgaard, W., H.B. Clausen, N. Gundestrups, C.U. Hammer, S.J. Johnsen, P.M. Kristindottir, and N. Reeh. 1982. A new Greenland ice core. Science 218:1273-1277.

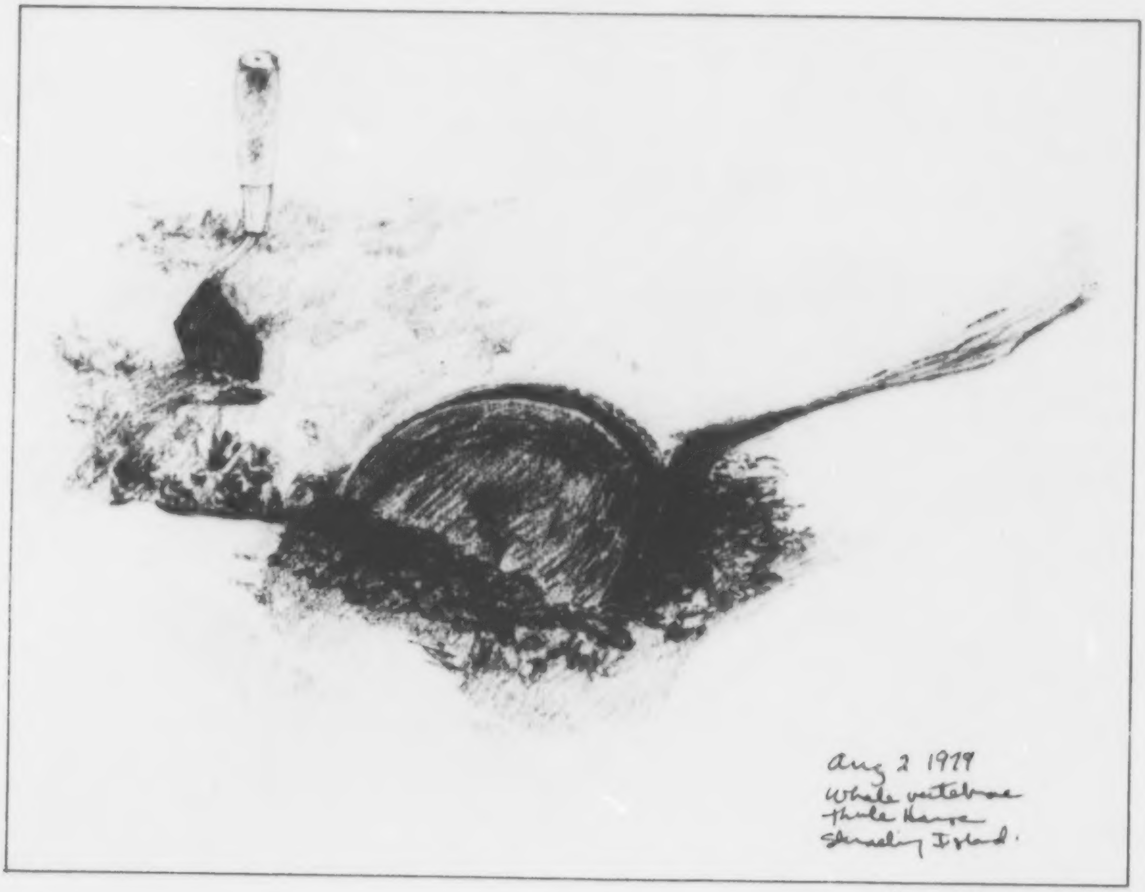
Hammer, C.U., H.B. Clausen, and W. Dansgaard. 1980. Greenland ice sheet evidence of post-glacial volcanism and its climatic impact. Nature 288:230-235.

Illustrated by Brenda Carter


♀ bobs + stretches head
if ♂ are attacking each other.

Illustrated by Brenda Carter

THE ATMOSPHERE



Aug 2 1979
Whale vertebrae
Thule House
Skraeling Island.

Illustrated by Brenda Carter

CLIMATE AND THE CANADIAN ARCTIC ISLANDS

Gordon A. McKay[1]

Abstract: The Arctic climate is harsh by southern Canadian standards but normal for the Inuit. The climate reflects the polar-region energy exchange, and the weather systems that cross the area. Brief summers with long daylight bring welcome periods of warmth and energize the vigorous Arctic microclimates. They also bring thawing soils and hordes of insects. Snowcover and the relative absence of solar radiation contribute to the extreme cold and length of winter. Although cold, wind and drifting snow may curtail activity, winter is often the favoured season for travel since the water and land are both firm. Storms are often most severe near sea coasts where snow and gales may cut access to harbours and settlements and complicate travel in ice-fields. Strong temperature gradients and abundant snow occur in winter across the eastern Arctic. Very light precipitation farther west has led to the expression "polar desert".

Today, much attention is being given to atmospheric change resulting from human activity. "Arctic haze" and climate-warming as a result of the "greenhouse" effect could have enormous impact. Current projections indicate Arctic winters may be up to 10°C warmer by 2050 - much greater than southern-latitude warming. Summer warming would be less, but both the growing and ice-free seasons would be extended, precipitation would increase as would the sea level. Such alterations would greatly affect people, ecosystems and travel within the Arctic.

Résumé: Le climat de l'Arctique paraît rigoureux pour les habitants du sud du Canada, mais normal pour les Inuits. Ce climat est fonction de l'échange d'énergie solaire et thermique de la région polaire et des systèmes météorologiques qui traversent la région. De brefs étés marqués par de longues périodes de lumière du jour apportent une chaleur opportune et stimulent les vigoureux microclimats de l'Arctique. Ils s'accompagnent aussi d'un dégel du sol et d'une multitude d'insectes. La couverture de neige et l'absence relative de rayonnement solaire contribuent au froid extrême et à la longueur de l'hiver. Même si le froid, le vent et la poudrerie risquent de réduire l'activité, l'hiver est souvent la saison préférée pour les voyages, car l'eau et le sol y sont tous les deux à l'état solide. Les tempêtes sont souvent les plus violentes près de la côte, où la neige et les vents forts peuvent couper l'accès aux ports et aux collectivités, ainsi que compliquer les déplacements dans les champs de glace. Dans tout l'est de l'Arctique, il y a en hiver de forts gradients de température et une neige abondante. Plus à l'ouest, des conditions marquées par de très faibles précipitations ont donné naissance à l'expression "désert polaire".

Aujourd'hui on s'intéresse beaucoup au changement atmosphérique attribuable à l'activité humaine. La "brume arctique" et le réchauffement du climat découlant de l'effet de "serre" pourraient avoir d'énormes répercussions. D'après des projections actuelles, en l'an 2050, les hivers arctiques seront peut-être jusqu'à 10°C plus chauds qu'aujourd'hui, réchauffement nettement supérieur à celui du sud. Le réchauffement d'été serait moins élevé, mais tant la saison de croissance que la saison exempte de glace s'allongeraient, la hauteur des précipitations s'accroîtraient et le niveau de la mer monterait. De tels changements auraient d'énormes répercussions sur les gens, les écosystèmes et les déplacements de l'Arctique.

INTRODUCTION

Climate is a major determinant of the character of a region, and it is part of a global system. For example, the Sahara, the Great Plains and Amazonia all reflect strongly their regional climates. The imprint of climate on the Arctic Islands is unmistakable. Arctic climate has challenged mankind throughout history. Cold, ice, permafrost and the effects of an extreme environment on the human body and psyche have been major challenges. Animal and plant life have adapted to the rigors of climate, but occasionally are victims of extremes such as excessive windchill, the occurrence of glaze-ice and an excess or deficiency

---

[1] 122 Brooke Street, Thornhill, Ontario L4J 1Y9

of snowcover. Technologies and materials that are imported into the Arctic were often developed for use in quite different climates. That mismatch has led to many difficulties.

Scientific definition of the Arctic climate began with early expeditions. Posts of the Hudson's Bay Company and the Royal Canadian Mounted Police, provided climate information on a network basis. A formal meteorological network with upper-air soundings was instituted with the establishment of joint Canadian and American weather stations during the Second World War. The existing Canadian network, not only serves the requirements for weather forecasting, but at some locations the atmosphere's chemical composition is measured also, so that changes effected by man might be better understood. The historic and official networks enable the description of the broad features of climate in the Arctic Islands. The complex areal details of those features are now being revealed as supplementary records taken by teams of scientists, oil companies and others fill in the picture.

THE SYNTHESIS OF CLIMATE

The Arctic's climate is relatively unique. It reflects the astronomical control of the sun manifest in terms of incoming and reflected radiant energy and in weather systems. The snow and encompassing water and ice-cover also profoundly influence the climate. Most solar energy incident on snowcover is reflected back to space (Table 1). An appreciable fraction of the remainder is used in the melting and evaporation of snow and ice. The

TABLE 1: REFLECTION COEFFICIENTS FOR TYPICAL SURFACES (after Kondrat'ev 1954, Fritz 1951).

SURFACE	REFLECTIVITY in %
Exposed, continuous snowcover	80
Exposed, melting snowcover	55
Wet, after snow-melt	15
Tundra in the warm season	25
Coniferous forest	12
Complete stratocumulus cloud-cover	56 to 81

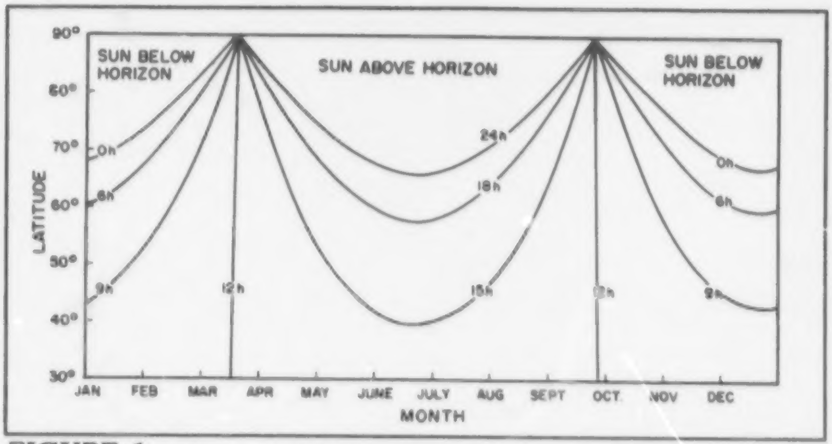


FIGURE 1: Duration of daylight (hours).

energy used in melting or stored in the oceans in summer is not lost, but is released to the atmosphere later as winter sets in. The potential energy input from the sun in mid-summer is similar to that at temperate latitudes, but the daylight period is much longer and the sun at a much lower angle than found farther to the south (Figure 1). The snow surface radiates energy back to space as a black body, resulting in steady net losses over the protracted winter and contributing to the formation of highly-stable cold air-masses. The net result is a long, cold winter and a short, cool summer.

Not only the frozen seas, but also the Atlantic and Pacific Ocean leave their mark on the climate. The eastern Arctic is mildest and receives most precipitation because of the nearby open water of the North Atlantic Ocean. The western regions are much drier, and the northwest is strongly influenced by the adjacent multiyear ice cover of the ice-covered Arctic Ocean (see Jeffries *et al.*, this volume).

Land relief and surface-cover also helps to shape climate. Mountains act as barriers to air flow, stimulating precipitation on their windward side, and contributing to warmer, drier climates downwind (see Alt and Maxwell, this volume). They produce katabatic and foëhn winds. Along with wind, mountains serve to augment or to decrease precipitation. On one occasion International Biological Program scientists on Devon Island observed a marked foëhn wind accompanied by rapid snow-melt causing lemmings that had not moved to higher ground to drown. Cloudiness, precipitation and wind speeds generally increase with elevation, whereas air temperature and moisture content decrease. Under cooling conditions, colder air tends to flow into and accumulate in valleys, causing strong inversions that favour the accumulation of pollutants and the formation of ice-fog. The acceleration, damming and deflection of air due to topographic features can produce unusual local climates or microclimates. The surrounding sea ice reaches its greatest extent in April, at which time its surface features may be indistinguishable from adjacent land (Mckay *et al.* 1970).

LESSONS OF HISTORY

Impacts of Climate Variations

Overcoming the difficult Arctic climate has challenged generations of explorers. The opening of the Arctic with European exploration and its subsequent exploitation occurred during periods of relatively benign climate. Iceland became a centre of western culture during climate-warming in the ninth and tenth centuries. Its fortunes shifted in phase with subsequent warming and cooling. Thousands of Icelanders emigrated during the cold spell that lasted from 1870 to 1918. As the climate warmed in the first part of the twentieth century, a major cod fishery (408,000 tonnes peak) opened in 1917 west of Greenland, to be drastically reduced in the 1960s as a result of cooling climate (Cushing 1979; Wallén 1986). Lamb (1985) has noted that the optimum temperature for cod is between 4 and 7°C: they cannot exist in water colder than 2°C. The opening of the Eastern Passage to the north of the Soviet Union occurred in the 1930s when warming reached a peak. Fears were expressed then should the climate revert to normal. Subsequent technological change has helped compensate for the extreme climate. Nevertheless the entrapment of the Soviet vessels in heavy ice north of Siberia in the winter of 1982-1983 demonstrated continuing vulnerability. Certainly the return to a colder climate reversed hopes for agriculture in the Kola Peninsula that were raised in the 1930s when many new plant species were introduced there (Kovda 1980). More recent cool intervals in the 1960s have also caused great stress in Iceland, reducing agricultural production (15% loss for 1°C cooling), displacing the herring fishery, and leading to currency devaluation (McKay *et al.* 1980). The importance of such climate variations must be kept in mind. However, another factor must also be considered - the possibility of climate-warming as a result of atmospheric changes caused by human activities.

THE SEASONS

Winter dominates the Arctic scene. Defined as that period when the mean air temperature remains below 0°C, it lasts over 300 days in northern Ellesmere Island and 275 days near latitude 70°N (Figure 2). Precipitation over much of the Arctic Archipelago is very light (Figure 3), heavier snowfalls occurring in those areas exposed to winds from open oceans. Snowcover and the relative absence of solar radiation contribute to the extreme cold and length of winter. Although cold, wind and drifting snow may curtail activity, winter is often the favoured season for travel since the ground is solid and ice covers the waters. The summers are cloudy and cold partly because of the extensive ice that covers the polar seas (Figure 4). Microclimates play a major role in plant growth that is needed for wildlife survival. Storms are rare in summer, and the weather is frequently clear and void of haze.

Temperature

January mean daily minimum temperatures average between -25 and -38°C, the coldest region being the M'Clintock Channel - King William Island area. The daily range is not great, averaging about 8°C. The cold is steady and intense, however, the moderating effect of the Arctic ice becomes readily apparent. The oceans exert a moderating influence on temperature, even through the sea ice, so that more extreme low and high daily values are found in continental areas to the south. Island winters do not produce the extreme low temperatures found in some more continental areas, such as Snag, Yukon where the temperature has fallen to -62.8°C. The winter cold is steady as noted in Table 2.

TABLE 2: MEAN DAILY TEMPERATURE °C

	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Gladman Pt.	-23.6	-30.0	-34.7	-35.0	-32.2	-22.5
Mould Bay	-26.6	-31.2	-33.5	-35.2	-32.8	-24.1
Pond Inlet	-25.1	-28.4	-30.7	-32.7	-31.1	-21.7

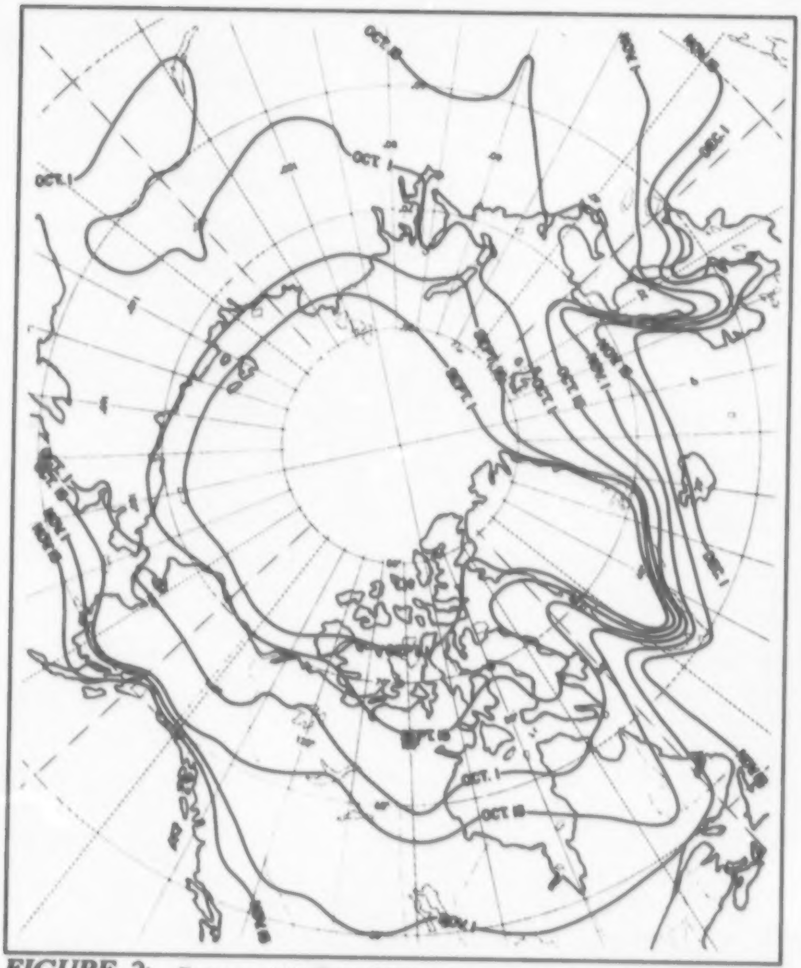

OCT 15
NOV 1
NOV 15
DEC 1
OCT 1
OCT 1
SEPT 1
SEPT 15
OCT 1
OCT 15
NOV 1
NOV 15
DEC 1
SEPT 15
OCT 1
OCT 15
NOV 1
NOV 15
NOV 15
NOV 1
NOV 15

FIGURE 2: Date on which mean daily temperature falls below 0°C (McKay et al. 1970.

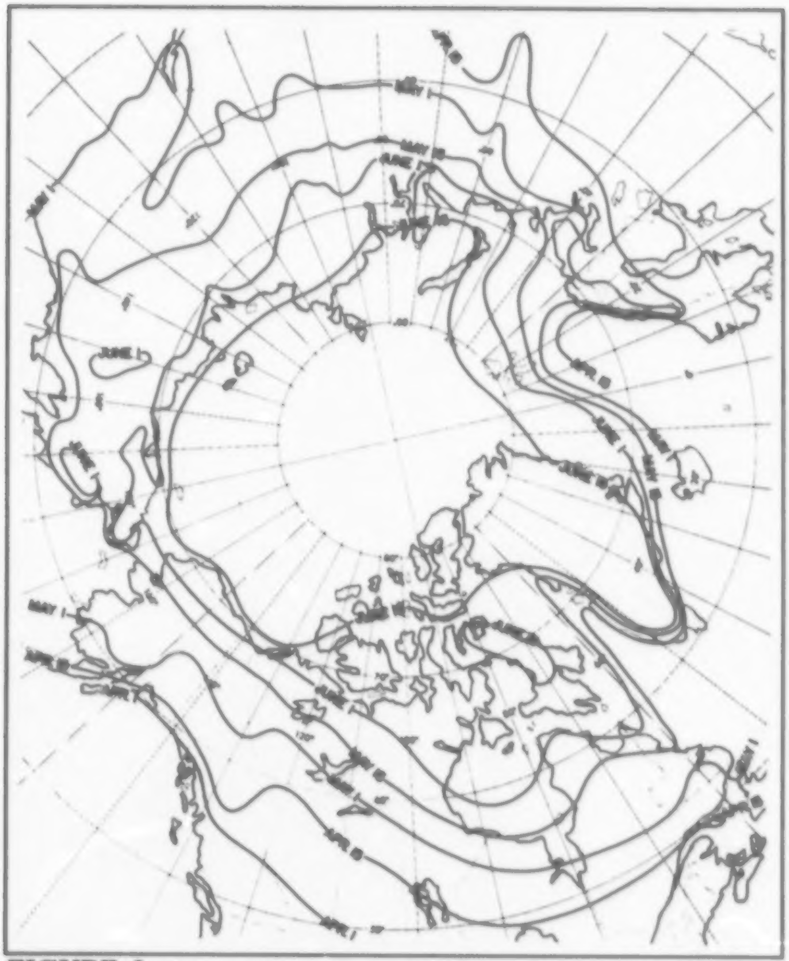

MAY 1
MAY 15
JUNE 1
JUNE 15
APR. 15
APR. 1

FIGURE 3: **Date on which mean daily temperature rises above 0°C (McKay et al. 1970.**

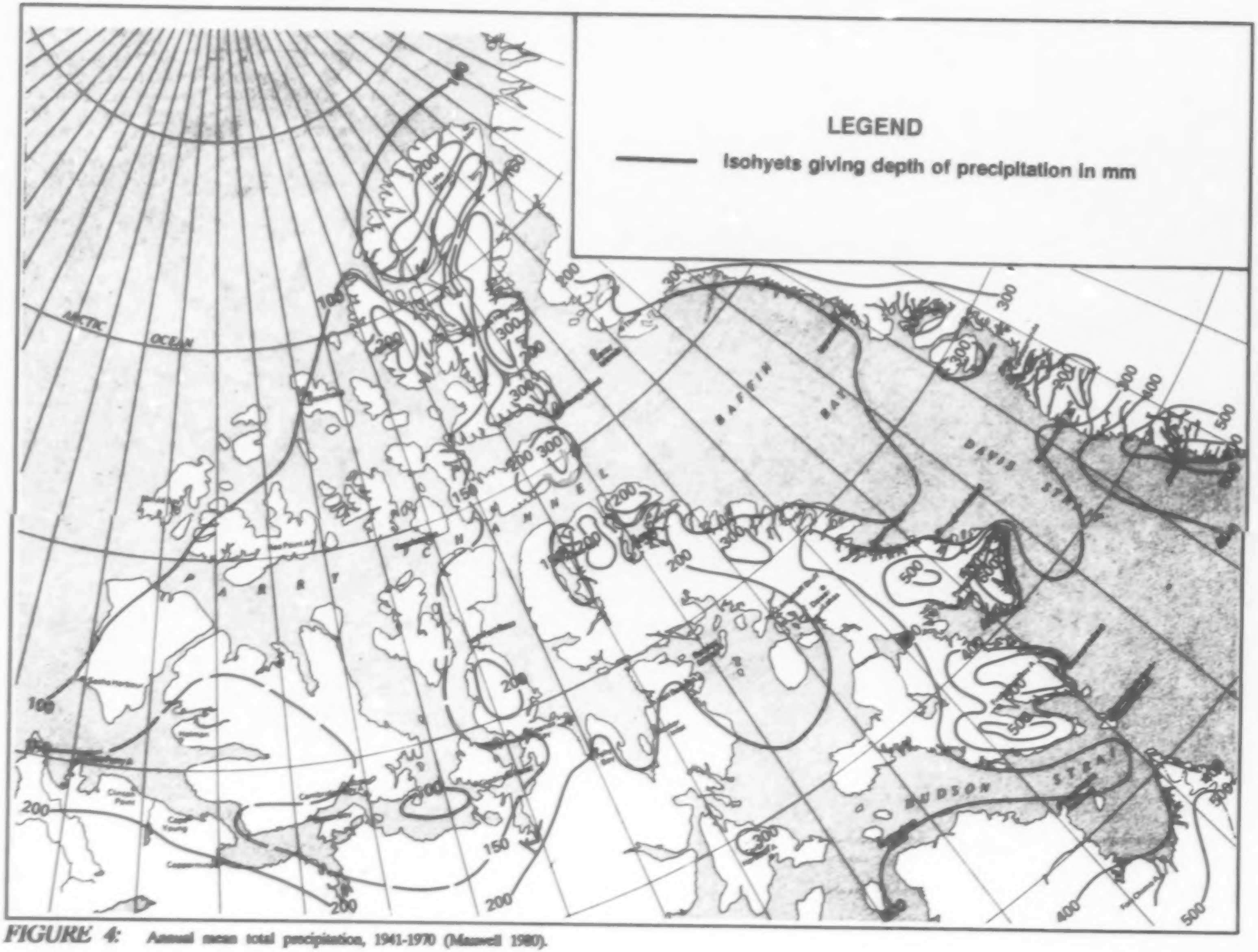

LEGEND
Isohyets giving depth of precipitation in mm
ARCTIC OCEAN
BAFFIN BAY
DAVIS STRAIT
HUDSON STRAIT
PARRY CHANNEL
100
150
200
300
400
500

FIGURE 4: Annual mean total precipitation, 1941-1970 (Maxwell 1980).

TABLE 3: MEAN DAILY TEMPERATURE °C

	May	June	July	Aug.	Sept.	Oct.
Cambridge Bay	-9.	1.5	7.9	6.5	-0.7	-11.7
Arctic Bay	-8.0	1.5	5.6	4.6	-1.7	-11.4
Eureka	-10.7	1.8	5.4	3.3	-8.3	-22.1

The 'free-air' mean July maximum temperatures average about 10°C in Victoria Island and southwestern Baffin Island to 5°C northwest of the Queen Elizabeth Islands. The mean July temperature 10°C isotherm roughly conforms with the mainland treeline. Across the islands the daily range averages about 7°C. With the disappearance of snowcover, temperatures rise inland from the marine ice fields, and maxima have reached 29°C at Cambridge Bay, 24°C at Frobisher Bay and 19°C at Eureka.

Over land covered by ice sheets, no months of the year have mean temperatures above freezing, and there is no significant diurnal range of temperature. Lowest temperatures occur at the end of the dark period. Melting occurs a few days in summer.

Precipitation/Snow Cover

Most precipitation is due to cyclonic storms, but frost and rime also contribute to the accumulation. Snowfall is by far the most common form and snowcover the dominant feature. In addition to being a product of climate, snowcover also shapes the climate. Annual precipitation is generally less than 350 mm and is primarily due to cyclonic storms. Frost and snow occur in every month and snow covers the ground about 10 months of the year (Figure 5). Snowcover is hard, dry and quite variable in depth. It averages 30 cm depth inland, but a vast portion of the barren lands in Arctic Canada accumulate relatively little snowcover and are referred to as a polar desert. Snowcover has a vital role to play in protecting plants and rodents from the cold and winds as well as contributing to their water supply. On the other hand it is an obstacle to grazing caribou. The snow-depths increase toward sea coasts reaching about 300 cm on exposed mountain slopes.

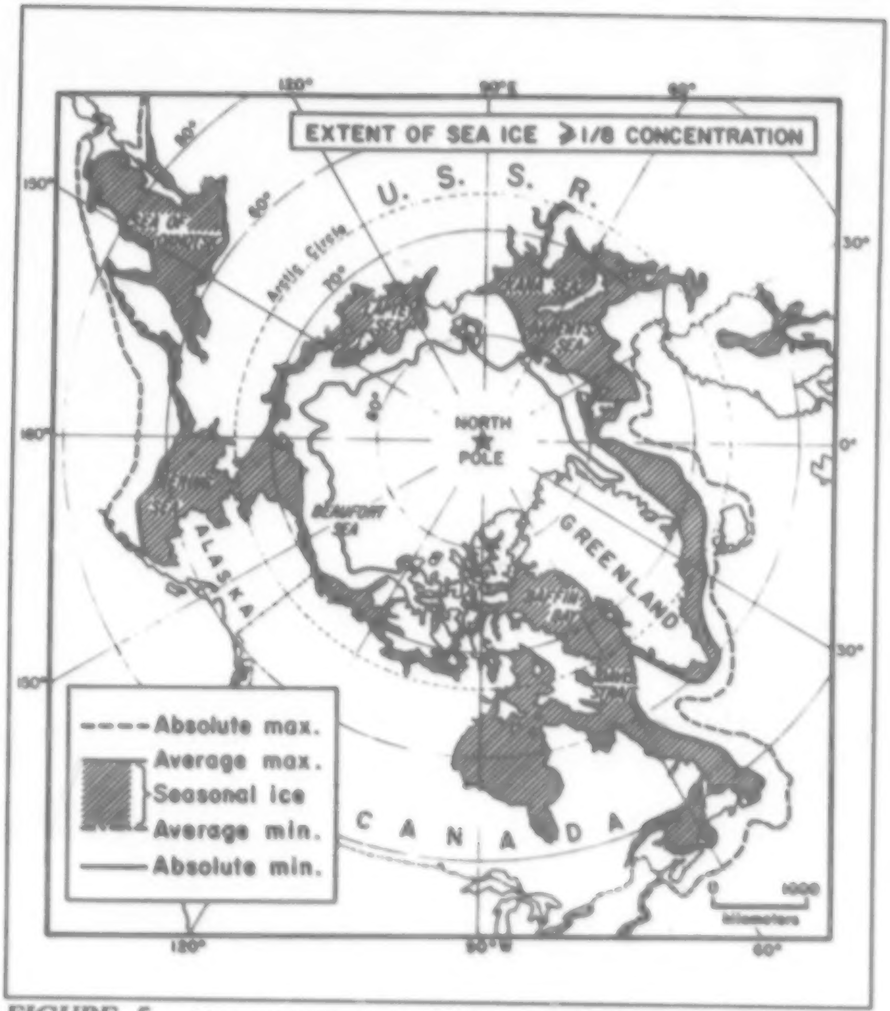

EXTENT OF SEA ICE ≥1/8 CONCENTRATION
U. S. S. R.
Arctic Circle
70°
80°
LAPTEV SEA
KARA SEA
BARENTS SEA
NORTH POLE
BERING SEA
ALASKA
BEAUFORT SEA
GREENLAND
BAFFIN BAY
DAVIS STRAIT
CANADA
120°
90°E
60°
150°
30°
180°
0°
90°W
----Absolute max.
Average max.
Seasonal ice
Average min.
——Absolute min.
0 1000
kilometers

FIGURE 5: Mean and extremes of variable sea ice ≥1/8 concentration in the northern hemisphere (Barry 1983).

Storms

Storms are often severe near the coasts where supergradient winds may occur when extremely cold air comes in contact with the open ocean. There, snow and gales may frequently cut access to harbours and settlements and complicate travel in ice-fields. Winter storm winds in excess of 50 kts and gusts of over 100 kts are sometimes reported. Winds at Cape Hopes Advance were recorded in excess of 100 kts over a 5-hour period and averaged 125 kts over 1 hour in a November 1931 storm (Archibald 1969). Concurrent winds of 83 kts and a temperature of -30°C were recorded at Winter Harbour. Gales have driven seas inland, flooding low-lying areas, and strong winds have blown away buildings at Port Burwell and Alert. The combination of drifting and blowing snow under severe wind conditions threaten wildlife and humans alike. The presence of sea ice prevents or mitigates surge and high-waves.

Variability

Variability is a normal feature of every climate and, as noted above, the Arctic is no exception. There are marked variations in climate from season to season and year to year. Interannual and long-term variability is even more marked than that found to the south. Warming in the early part of this century was much more intense in the Arctic than the South. The variations in climate are reflected in the extent and thickness of sea ice, the formation and melting of which is highly correlated with air temperatures. As in the South, the extremes of climate are of great importance. The severely-cold winters cull out less hardy biota and critically test human designs and structures. For example, exceptionally deep snowcover over nesting grounds resulted in large losses of geese in 1972. Unusual drought, winds, snowcover, ice-storms and thaws have all taken their toll.

ATMOSPHERIC CHANGE

The climate of the Arctic has changed dramatically over time. The fossil dawn redwoods of Axel Heiberg Island, ice-covered peat on Ellesmere Island, and driftwood found on raised beaches in Greenland and surrounding Hudson Bay attest to dramatically different climates in the past. The noted opening of the Eastern Passage north of the Soviet Union and the rise and decline of the cod fishery off west Greenland give evidence of notable short-term changes within recent history. Climate projections for the future introduce a new dimension because of dramatic alteration of the chemical composition of the atmosphere as a result of human activity. Historically the effects of man have been local. Now they have become a global issue of much concern.

Chemical Change

The climate-system is gradually being transformed by human activities. Most notably, the atmosphere has been used as a sump, receiving and transporting chemical emissions from a wide range of industries. Major contaminants include CO_2, CFCs, CH_4, SO_x, NO_x, other radiative gases and emissions that contribute to acid-rain and tropospheric ozone as well as toxic depositions. These emissions have led to major atmospheric changes manifest in acid and toxic depositions and in the ozone hole over Antarctica. Add to those effects the implications of greenhouse-warming, arctic haze, desertification and other massive land-use changes, and the assault on the climate-system is seen to be enormous - with major implications for the Canadian Arctic Islands.

The relative absence of precipitation-scavenging (liquid and solid precipitation are highly effective in removing air pollutants) and the existence of strong atmospheric inversions have been blamed for the net accumulation of pollutants such as sulphates, mercury, cadmium, vanadium and manganese in the Arctic. Their sources are primarily the industrialized areas to the south. The pollutants, along with particles from other land and oceanic sources, form an "Arctic Haze", which is widespread and well-mixed. The concentration shows strong seasonality, the winter peak attaining levels that are 20 to 40 times greater than in summer. The haze is acidic, being about 30% sulphate, but the levels of acidity are still 10 times lower than in industrialized areas to the south (Rahn 1980). Arctic pollution can be exacerbated locally (e.g., emissions at airports). That pollution, too, shows strong seasonality, and depositions can be episodic depending on precipitation, boundary-layer wind speed and direction, and the duration of stagnant periods. Both local pollutants and those transported over long distances alter the reflective and radiative properties of the snowcover and the atmosphere. Since the ground is snow-covered most of the time, there is little convection and ventilation is poor in the absence of storms. Pronounced inversions that persist all day in valleys, coupled with the incapacity of the cold air to hold significant quantities of moisture, can result in locally intense concentrations of pollutants and increased frequencies of ice-crystal fogs.

The "Greenhouse" Effect

Much has been written and said of warming of the Arctic due to the so-called "greenhouse" effect. Is it real? In 1979 the U.S. Academy of Sciences stated: "we have tried, but been unable to find any overlooked or underestimated physical effect that could preclude the currently estimated global warming due to a doubling of CO_2 .... We cannot exclude the possibility of some mitigating effect – but, nor can we exclude the possibility of more continuous and drastic changes." (U.S. National Research Council 1979).

Many gases contribute to the "greenhouse" effect. Most widely recognized is CO_2 which has increased from about 280 in 1850 to about 350 ppmv at present. CFC 11 has increased from zero to 0.24, and CFC 12 to 0.42 ppb over their period of use. The increase in methane is accredited in part to increases in populations of cattle, the cultivation of rice, and other land-use changes that show no signs of reversal.

There is now widespread acceptance that global climate has already warmed about 0.5°C as a result of human activities and that a 3°C warming (about $4W/m^2$) is possible within the next 70 years. The warming effect will be amplified at high-latitudes due to the strongly positive feedback effects to albedo alteration as the duration and area of snowcover diminishes, and as a result of modification of the marked atmospheric temperature inversions found in the Arctic (reduced vertical mixing of increased warmth). The greatest warming would be in winter, January surface-warming being about four times that of the tropics. Much of the additional summer thermal energy would be used in melting snow and ice, and stored in the surrounding ocean. The release of the stored heat from the ocean and the heat of fusion would contribute to moderation of winter temperatures. Extensive cloud might prevail in summer, reflecting incoming solar radiation in much the same manner as snowcover - a factor that requires closer investigation. Much increased precipitation is expected, and that too could complicate projections for some areas. Ice sheets might increase, and the snow-free period be relatively unchanged in those areas experiencing significantly increased snowfall and increased cloudiness.

CONSEQUENCES OF CHANGE

Rough estimates of response to climate can be made for biomass production, duration and thickness of ice-cover, duration of the growing and ice-free season, etc. The following are very generalized speculations on the consequences of such projected changes. They are based on indicated changes in the annual means of climatic parameters. Admittedly seasonal values could be superior, but their subjective nature makes more detailed projection unwarranted.

Climatic analogues (Figure 6) and regressions involving climate-parameters were used by McKay and Baker (1986) to assess the effects of a warming of about 2°C in summer and 10°C in winter. The regressions indicated that:

(1) biomass production approximately doubles for every 10°C increase in mean air temperature assuming no moisture constraint (Lieth 1973).

(2) the mean annual position of the edge of the sea ice tends to follow the 0°C isotherm of annual mean daily air temperature.

(3) the peak thickness of ice is largely a function of air temperature and can be estimated using degree-day techniques. Two-metre ice thicknesses are found with mean annual temperatures of about -16°C, and 1 m thickness with temperatures of about -2°C in regions that are unaffected by local phenomena.

(4) freeze-up and break-up dates of ice in bays and lakes are related to the annual temperature regime. Spatial variations generally reflect the mean annual temperature patterns, but marked exceptions occur near very large, deep-water bodies. The date of break-up tends to be advanced four days in spring and delayed three days in autumn for every 1°C increase in the annual mean daily air temperature.

(5) snowcover tends to disappear when the daily mean temperature reaches 3°C in spring, and to reform when the daily mean temperature drops below -0°C.

(6) the southern limit of discontinuous permafrost follows the -1°C annual mean daily air temperature isotherm; the edge of continuous permafrost the -8°C isotherm under present "steady" climate conditions. Warming of the permafrost would lag greatly behind atmospheric warming.

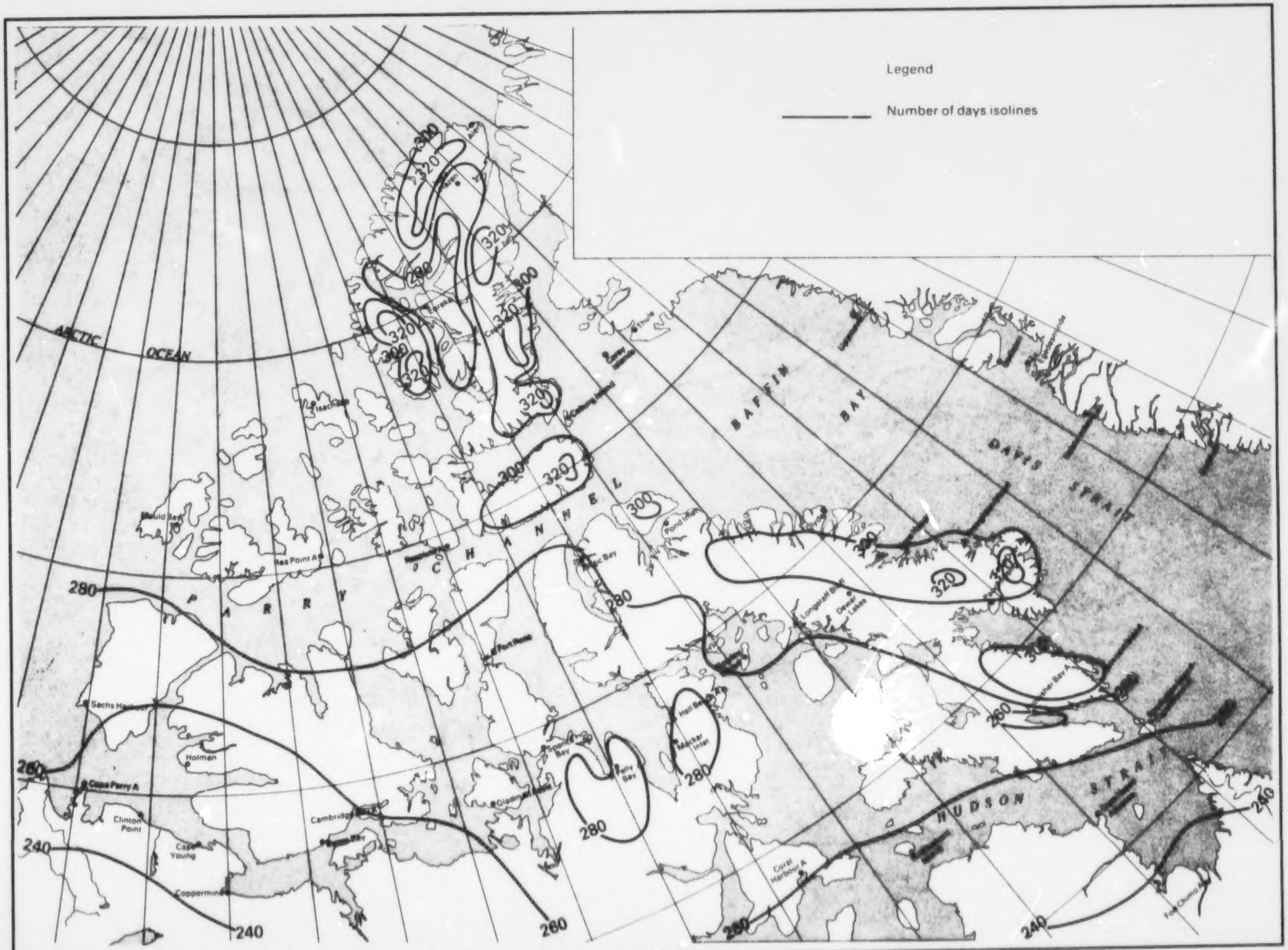

Legend
Number of days isolines
ARCTIC OCEAN
BAFFIN BAY
DAVIS STRAIT
HUDSON STRAIT
PARRY CHANNEL
Thule
Resolute
Res Point A
Mould Bay
Sachs Harbour
Holman
Cape Parry A
Clinton Point
Cape Young
Coppermine
Cambridge Bay
Spence Bay
Pelly Bay
Hall Beach
Mackar Inlet
Longstaff Bluff
Dewar Lakes
Pond Inlet
Coral Harbour A
Fort Chimo A
240
260
280
300
320

FIGURE 6: Mean duration of snowcover of at least 2.5 cm, 1955-1972 (Maxwell 1980).

The analogues are based on estimates of temperature and precipitation obtained using numerical models. They indicate a poleward migration of climatic isolines of about 1,100 km for a doubling of the concentration of atmospheric CO_2.

Marine Transportation

The most apparent physical effect of climate-warming is the reduction in coverage and thickness of sea ice. Navigation seasons could be extended by about six to seven weeks, and the peak thickness of ice reduced by about 20 cm by 2050. Should that occur, the warming process would be expected to continue and an ice-free Arctic is projected to follow - say by 2200. With the doubling of CO_2, navigation along the three access routes to the Arctic - the Mackenzie River, Hudson Strait and through Davis Strait and Baffin Bay to Parry Channel would be lengthened by one to two months. The Hudson Bay route would be open from early July to mid-November. At Iqaluit (formerly Frobisher Bay) the harbour would probably be clear of ice from mid-June to mid-November, at Resolute from early July to mid-October. The Davis Strait route would be open to small, unsupported craft for two and a half months compared to the present duration of a month. Both shipping and icebreaker operations would be facilitated by the thinner ice and shortened season. Icebergs and fog would continue to be major hazards along the route. Coastal shipping from the Mackenzie Delta and offshore drilling conditions would be significantly enhanced by the increase of about six weeks in the length of the navigation season.

Ice-cover would be general in winter, but less extensive in summer. It would be thinner and more easily traversed by strengthened ships. Transportation from the Pacific to the Atlantic via the North-West Passage could be much more feasible than at present. The reduction in pack and floe ice could make viable many projects that are now presently uneconomic. Similarly the opening of coastal areas for longer periods and with thinner ice could result in altered routings, port development, and less costly port and ship construction and maintenance. The reduced ice hazard offshore, warmer operating conditions and much improved sea transportation conditions would be a boon to the energy and mineral resources sectors. The costs of ice-breaking and constrained use for ships and facilities are part of the climate penalty. Some of the major energy fields are within the Queen Elizabeth Islands where ice-fields can be severe. But the actual result is unpredictable being dependent on technology, geology and markets as well as climate. Assuming a favourable supply/demand situation, a warmer climate will enhance viability and profitability.

Another aspect of climate-warming is that sea levels will increase as the volume of the ocean waters expand. This poses the problem of increased coastal flooding. Inland, there would be a slow poleward migration of permafrost, and increased land-use problems due to thawing of the active layer.

Implications of Altered Access

Access to resources (oil, gas and minerals) and markets is of great economic importance. Overcoming climate and climate-related hazards contributes significantly, along with distance, to the cost of resource exploration, extraction and transportation. Operations and maintenance can be costly because of the remoteness of sites, routes that are encumbered by ice and snow, construction that is affected by permafrost, and the performance of materials, vessels, machines and people in extremely cold environments. An additional cost is that of stockpiling (inventory) - necessitated by the seasonal nature of transportation. Lengthening the shipping-season would reduce these costs and thereby increase the viability of many Arctic operations.

A related factor is the probability of greatly increased Arctic maritime travel (Figure 7). Several nations have shown their interest in using the North-West Passage for scientific, military and commercial travel. That interest would greatly increase given more favourable marine and climate conditions. The result would be a need for adequate docking facilities, port, vessel and environmental security, navigation aids, search and rescue and enforcement capabilities. Canada's responsibilities for the Northwest Territories would necessitate a much increased presence and control. The projected opening of the Arctic to travel would have negative effects as well, exposing native peoples to increased pressures from the south.

Interrelationships

A warming Arctic would have major implications for the regions to the south. This would be directly apparent in the tempering of "Arctic outbreaks" over southern Canada. The north-south temperature gradient would be diminished, resulting in fewer intense weather fronts in temperate latitudes and decreased winds. The ice free-season in Hudson Bay would be increased. The altered climatic regimes and runoff would similarly alter the

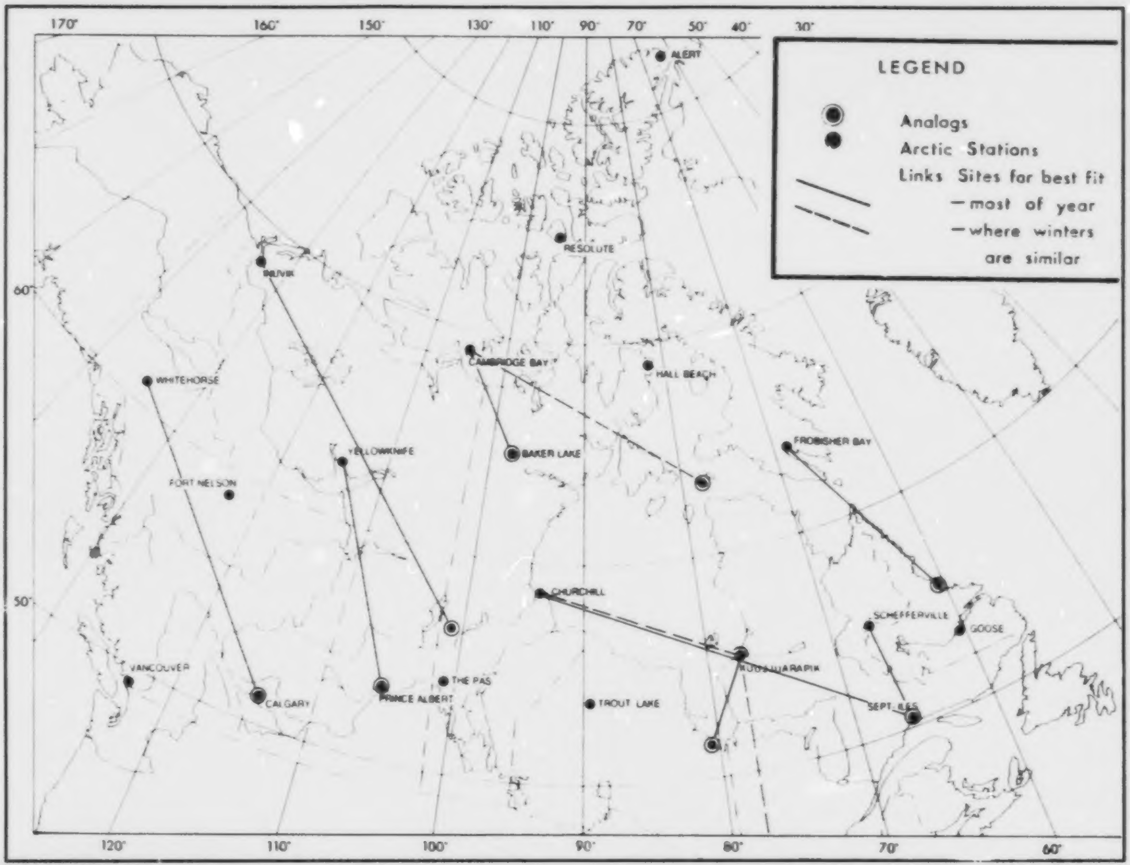

170°
160°
150°
130°
110°
90°
70°
50°
40°
30°
LEGEND
Analogs
Arctic Stations
Links Sites for best fit
— most of year
— where winters are similar
ALERT
RESOLUTE
INUVIK
CAMBRIDGE BAY
HALL BEACH
WHITEHORSE
YELLOWKNIFE
BAKER LAKE
FROBISHER BAY
FORT NELSON
CHURCHILL
SCHEFFERVILLE
GOOSE
KUUJJUARAPIK
VANCOUVER
CALGARY
PRINCE ALBERT
THE PAS
TROUT LAKE
SEPT-ÎLES
60°
50°
120°
110°
100°
90°
80°
70°
60°

FIGURE 7: **Present-day analogues of projected temperatures for northern Canada following a doubling of CO^2 in the atmosphere (McKay and Baker 1986).**

character of estuarine and ocean currents - resulting in yet another array of positive and negative feedbacks of significance to the High Arctic. Much research is required before such changes can be considered as more than speculations; however, there is wide consensus that significant change will occur within the next 50 or 60 years. A much better understanding of the nature and consequences of such changes is a vital requirement for planning the future of the Canadian Arctic Islands.

CONCLUSIONS

(1) The Climate of the Arctic Islands is generally seen as cold and forbidding with winter dominating the scene.

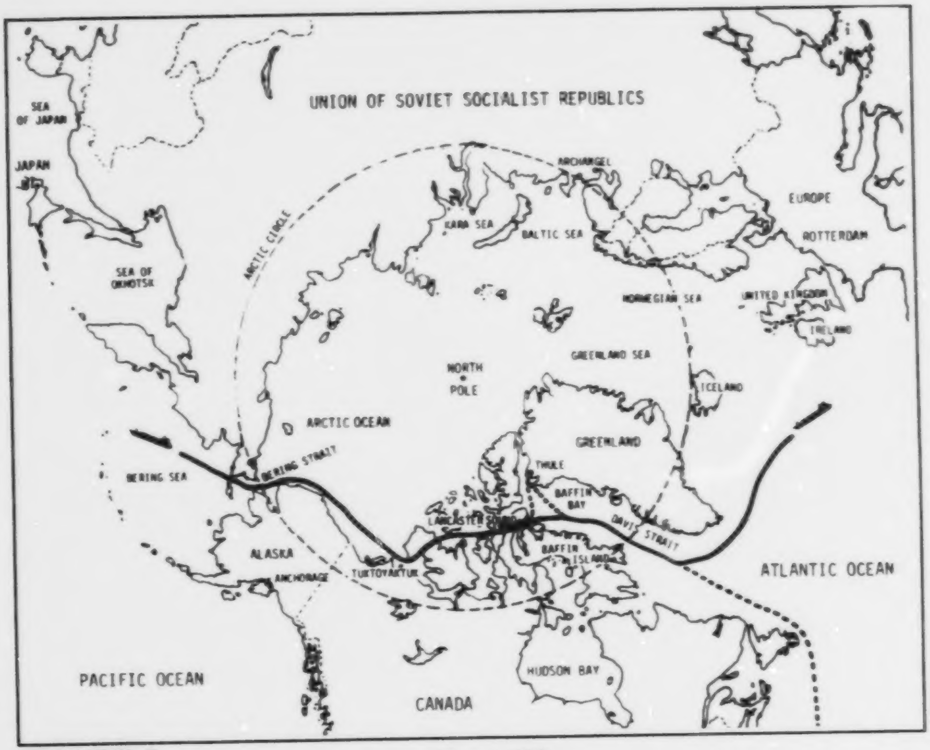

SEA OF JAPAN
JAPAN
UNION OF SOVIET SOCIALIST REPUBLICS
ARCHANGEL
EUROPE
ROTTERDAM
ARCTIC CIRCLE
KARA SEA
BALTIC SEA
SEA OF OKHOTSK
NORWEGIAN SEA
UNITED KINGDOM
IRELAND
GREENLAND SEA
NORTH POLE
ICELAND
ARCTIC OCEAN
GREENLAND
BERING STRAIT
BERING SEA
THULE
BAFFIN BAY
LANCASTER
DAVIS STRAIT
ALASKA
BAFFIN ISLAND
ATLANTIC OCEAN
ANCHORAGE
TUKTOYAKTUK
HUDSON BAY
PACIFIC OCEAN
CANADA

FIGURE 8: Arctic transportation routes (Burnet 1985).

(2) History discloses that the climate is variable and that changes at high latitude are greater than those experienced farther south. Furthermore, they show that climatic extremes are of critical importance for people and ecosystems. An altered climate will present a new set of extremes.

(3) Significant climate alteration may be in progress, and manifest itself clearly within a lifetime. This is likely because of chemical changes and radiative changes that affect the atmosphere. The projected effects of warming by such alteration are far greater that any recorded, and they could impose profound changes on people, ecosystems, and economies, having a major influence on maritime navigation, sea level, energy and mineral exploration, as well as plants and animals. Other changes due to chemical alteration are the depletion of protective stratospheric ozone and increased deposition of toxic chemicals and acidic ions. Their combined effects have profound implications for Arctic ecosystems and economies in the not-too-distant future.

(4) Much improved understanding of climate and of the way in which the land, sea and ecosystems respond to atmospheric and climate changes are needed in order to suitably plan for and adapt to such changes.

REFERENCES

Archibald, D.C. 1969. Intense storm tracks over Hudson Bay, the east Nova Scotia coast and the Grand Banks. Proceedings of the Calgary Ice Seminar, Canadian Institute of Mining and Metallurgy 8:1-9.

Barry, R.G. 1983. Arctic Ocean ice and climate: perspectives on a century of polar research. Annals of the Association of American Geographers 73:485-501.

Burnet, P. 1985. Paper sovereignty. Northern Perspectives (Canadian Arctic Resources Committee) 13:3, 1-7.

Cushing, D.H. 1979. Climate variation and marine fisheries. In: Proceedings of the World Climate Conference. World Meteorological Organization, Geneva, WMO No. 537:608-627.

Fritz, S. 1951. Solar radiation energy and its modification by the earth and atmosphere. Compendium of Meteorology, American Meteorological Society, Boston. pp. 13-33.

Kondrat'ev, K. 1954. The radiant energy of the sun. Chapter IX, Gidromet., Leningrad. English summary (Albedo of underlying surface and clouds) by A. Kurlents and P. Larsson, McGill University, U.S. Air Force Cambridge Research Laboratories AF 19(604)-7415. 28 pp.

Kovda, V.A. 1980. Land aridization and drought control. Westview Special Studies in Natural Resources and Energy Management. Westview Press, Boulder, Colorado. 277 pp.

Lamb, H.H. 1985. Climate and its variability in the North Sea, North-east Atlantic region. In: The North Sea - A Highway of Economic and Cultural Exchange. Starnizer Museum, Stavanger. pp. 27-38.

Lieth, H. 1973. Primary production: terrestrial ecosystem. Human Ecology (14):303-332.

Maxwell, J.B. 1980. The climate of the Canadian Arctic Islands and adjacent waters. Volume 1. Atmospheric Environment Service, Downsview, Canada. 531 pp.

______. 1982. The climate of the Canadian Arctic Islands and adjacent waters. Volume 2. Atmospheric Environment Services, Downsview, Canada. 589 pp.

McKay, G.A., T.R. Allsopp, and J.B. Maxwell. 1980. Lessons from the past. In: Proceedings, International Conference on Climate and Offshore Energy Resources. American Meteorological Society. pp. 21-37.

McKay, G.A. and W.M. Baker. 1986. Socio-economic implications of climatic change in the Canadian Arctic. In: Proceedings, Impact of Climatic Change on the Canadian Arctic, A Canadian Climate Program Workshop. Environment Canada. pp. 116-136.

McKay, G.A., B.F. Findlay, and H.A. Thompson. 1970. A climate perspective of tundra areas. In: Proceedings, Productivity and Conservation in Northern Circumpolar Lands. IUCN, Morges, Switzerland. pp. 10-33.

Rahn, K.A. 1980. Why is there arctic haze? A case study of geography, meteorology and demographics. Presented at: Conference on the Arctic Ocean. Royal Geographical Society, London. 11 pp.

U.S. National Research Council. 1979. Toward a U.S. Climate Program Plan, National Academy of Sciences, Climate Research Board, Washington, D.C. 124 pp.

Wallén, C.C. 1986. Impact of present century climate fluctuation in the northern hemisphere. Geografiska Annaler, Series A (Physical Geography), 68A(4):245-278.

Illustrated by Brenda Carter

THE QUEEN ELIZABETH ISLANDS: A CASE STUDY FOR ARCTIC CLIMATE DATA AVAILABILITY AND REGIONAL CLIMATE ANALYSIS

Bea Taylor Alt[1] and Barrie Maxwell[2]

Abstract: The Canadian Arctic Islands provide a unique challenge in the collection and analysis of climate data. The degree to which this challenge is being met is examined by reviewing the extent and means of accessing climate data for the islands as a whole and through a case study of regional climate data analysis in the Queen Elizabeth Islands (QEI).

Access to the Atmospheric Environment Service (AES) climate database and to various "non-standard" data sets has changed dramatically during the past dozen years. Complex analysis can now be routinely carried out either on request, or by individuals themselves using AES-developed computer information systems such as: MAST (Marine Statistics), LAST (Land Statistics), DUST (Duration Statistics), CONAN (Contour Analysis), CRISP (Sea Ice Data Analysis), CLASP (Standard Climate Applications Statistics) and SPASM (Pressure Centre Movement Analysis).

The case study employs standard and non-standard climate data from the QEI to examine regional climate and climatic controls in this data-sparse area. The study underscores the importance of using appropriate time and space scales in climate-related studies. Regional summer climate patterns over most of the QEI result from the interaction of major topographical features with persistent northwesterly flow off the cold central Arctic Ocean. A distinctive "S"-shape is seen in mean monthly sea-level plots of most summer-climate parameters. July maps feature 1°C temperatures and 80% cloud-cover along the exposed northwestern edge of the islands compared to 8°C temperatures and 60% cloud-cover at the same latitude in the intermontane region of central Ellesmere Island.

Future climate work in the Canadian Arctic Islands will not only require use of technological advances in remote-sensing and automatic weather stations, but also careful, detailed analysis of the varied data now available and continued cooperation between all agencies and disciplines working in the area.

Résumé: Les îles de l'Arctique canadien représentent un défi pour la collecte et l'analyse de données climatiques. On examine le succès remporté face à ce défi en étudiant la portée et les moyens d'accès aux données climatiques pour ces îles dans leur ensemble et par une étude de cas d'analyse par région de données climatiques dans les îles Reine-Élizabeth.

Depuis environ 12 ans, il y a eu beaucoup de changements dans l'accès à la base de données climatiques du Service de l'environnement atmosphérique (SEA), et à divers jeux de données non standard. L'analyse complexe peut maintenant facilement être faite soit sur demande, soit par les intéressés eux-mêmes, à l'aide de systèmes informatisés mis au point par le SEA, comme MAST (statistiques marines), LAST (statistiques terrestres), DUST (statistiques de durée), CONAN (analyse de contours), CRISP (analyse des données de glace de mer), CLASP (statistiques d'applications climatiques standard) et SPASM (analyse du mouvement des centres de pression).

L'étude de cas fait appel à des données climatiques standard et non standard sur les îles Reine-Élizabeth pour examiner le climat régional et les facteurs influençant le climat dans cette partie du monde où les données sont rares. Elle met en relief l'importance d'utiliser des échelles temporelles et spatiales appropriées lors des études portant sur le climat. Les configurations régionales du climat estival sur la presque totalité des îles Reine-Élizabeth résultent de l'interaction des principaux accidents topographiques avec le flux persistant du nord-ouest venant du centre de l'océan Arctique, qui est froid. Les courbes moyennes mensuelles au niveau de la mer de la plupart des paramètres du climat estival montrent une forme en "S" caractéristique. Sur les cartes de juillet, on voit des températures de 1° C et une nébulosité de 80 % sur la bordure nord-ouest, exposée, des îles et des températures de 8° C et une nébulosité de 60 % à la même latitude dans la région intramontagneuse du centre de l'île Ellesmere.

Dans l'avenir, les études sur le climat dans les îles de l'Arctique canadien feront appel non seulement à la technologie avancée de télédétection et aux stations météorologiques automatiques, mais aussi à une analyse soigneuse et détaillée des diverses données présentement disponibles, ainsi qu'à une collaboration soutenue entre tous les organismes et disciplines oeuvrant dans le secteur.

INTRODUCTION

The Canadian Arctic Islands provide a unique challenge in the collection and analysis of climate data. The degree to which this challenge is being met is the focus of this paper. Climatological data available for the Canadian Arctic Islands and access to those data are briefly described. Emphasis is placed, however, on a case study of regional climate data and analysis in the Queen Elizabeth Islands - that portion of the Canadian Arctic north of Parry Channel (Figure 1). This case study underscores the importance of interpreting such data on realistic time and space-scales. The results also provide an opportunity to point out gaps in the existing climate data-gathering system and how these might be overcome.

---

[1] Terrain Sciences Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8
[2] Canadian Climate Centre, Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ontario M3H 5T4
Geological Survey of Canada Contribution No. 15689.

Arctic Data Access

The Canadian Climate Centre (CCC), a component of the Atmospheric Environment Service (AES), is responsible for Canada's national archive of atmospheric data. This archive is quite diverse in terms of the types of information that are stored, the methods used to store them and the ways in which they can be accessed. All data collected at AES arctic stations are included and treated similarly to those from other regions of Canada.

Data stored in the archive for the Canadian Arctic are observed at stations which may be considered to belong to one or several of the different AES national networks (e.g. hourly and synoptic, daily climate, rainfall rate, sunshine, radiation, soil temperature, evaporation, upper air, freeze-up and break-up, snow survey, etc.) - the names suggesting the wide range of atmospheric and related elements observed in the Canadian Arctic. There are, however, wide variations in the density of arctic coverage within each network, and even where reasonable densities exist, there may be serious problems with representativeness of data. Arctic-station siting has often been more determined by logistical expediency than by optimal observing considerations. Currently, arctic climatological data are gathered commonly at manned stations, supplemented by automatic installations (some of which store data for later retrieval; others of which are capable of telemetering data for real-time use).

Table 1 provides an historical perspective on the development of the climate-observing network in the Arctic Islands, based on the AES Climatological Station Data Catalogue (AES 1981) for stations with digital data included in the national archive. For comparison, information on stations located at adjacent mainland coastal sites is included. The increase in numbers of stations resulting from the construction of the DEW line sites in the 1950s is evident. The decrease in the 1980s is a result of not only an upgrading of existing stations combined with the closing of nearby sites, but also a reduction in the number of oil and gas exploration sites whose data were put into the digital archive.

TABLE 1: HISTORY OF CLIMATE OBSERVING NETWORK[1].

[1] The number of stations in operation by decade are shown, both for stations exclusively in the Canadian Arctic Islands, as well as for sites along the adjacent mainland. The information is based on Atmospheric Environment Service station data catalogues and does not include stations operated by other government departments or by private industry.

	1880-1889	1890-1899	1900-1909	1910-1919	1920-1929	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979	1980-	Total # Diff. Stations
Arctic Island Sites	1	1	3	3	8	15	19	39	43	43	29	67
Mainland Sites	0	0	1	3	4	4	6	28	28	19	16	34
Totals	1	1	4	6	12	19	25	67	71	62	45	101

As alluded to above, while a significant portion of the national climate archive is retained in hard copy or micrographic form, the majority of the data is stored digitally. Within the digital archive, data are generally organized chronologically as daily records of hourly values, monthly records of daily values, and/or annual records of monthly values.

Access to these arctic digital data is possible in three ways: publications, custom jobs or direct access. Publications range from long-term normals to routine weekly, monthly and annual summaries to special-purpose studies with specific applications. These are all generally available on request.

Custom jobs are needed when the user's specific requirement cannot be met with available publications. Several programs (general report programs - GRPs) and information systems have been developed to meet this need. The latter are collectively known as the MAST suite of systems, MAST standing for MArine STatistics. The systems originated with the need to access ship observations for evaluating offshore climate; however, with time, new components have been added to the original system so that data can be addressed and analyzed for land stations (LAST), for duration and extreme-value analysis (DUST), for sea-ice data (CRISP), for deriving synthetic winds for data-sparse areas (WISP) and for the movement of surface-pressure centres (SPASM). Contoured output from these systems is accomplished through another compatible system (CONAN).

The recognized need to allow direct access to the AES climate archive, as well as the requirement to address more efficiently its ever-increasing complexity, size and quality control, aspects, resulted in the decision to develop a Climate Data Management System (CDMS). Objectives of the CDMS are: (1) to improve data capture; (2) to streamline quality-control; and (3) to allow access to current and archived data. When fully operational, this system will be easy to use, featuring online data entry, interactive quality, online check definition, document-tracking, reporting, archiving and data access. Integrated with CDMS will be a Station Information System (SIS) providing a complete record of station history (location, instrumentation, observing program and all changes).

An issue of particular concern for the Canadian Arctic and which is specifically addressed by CDMS is that of non-standard data (in effect, non-AES data). Until now, there was no policy that allowed for the integration of such information directly into the climate archive, so such data were dealt with on an ad hoc basis. This is a particular concern in the Canadian Arctic because, with data coverage that is generally sparse and of questionable representativeness in many cases, any additional data-gathering programs can be very valuable. Several specific data-sets provide good examples: the Polar Continental Shelf Project climate observations collected by scientific parties active during summer field-seasons (1972 on), regular weather observations taken by offshore operators in the Beaufort Sea during the summer-fall drilling season (1976 on), and data collected by the oil and gas industry at both land and on-ice sites at various locations in the Queen Elizabeth Islands (1973 on). At present, these are not technically part of the archive, but they are available in digital form as distinct data-sets which can be accessed through MAST.

THE QUEEN ELIZABETH ISLANDS

The Queen Elizabeth Islands (QEI) comprise that part of the Canadian Arctic generally lying to the north of 74°30'N (Figure 1). To the south, the QEI are separated from the rest of the Canadian Arctic Archipelago by Parry Channel, a broad waterway composed of M'Clure Strait, Viscount Melville Sound, Barrow Strait and Lancaster Sound. The northwestern edge of the Queen Elizabeth Islands, extending 1,450 km from southwestern Prince Patrick Island to northernmost Ellesmere Island faces the perennially ice-covered Arctic Ocean. The eastern QEI abut Greenland and its extensive ice cap across Nares Strait and northern Baffin Bay. In the northwestern and north-central QEI, sea ice fills the inter-island channels even in summer. In the east, the channels are navigable in late summer.

Climate-data collection in the QEI has had an interesting history resulting in a rather diverse set of observing programs that generally continue to this day. At the root of this are three primary considerations: (1) the basic severity of the climate itself; (2) the remoteness of the area; and (3) the politics defining which government agency is responsible for what activity in the region. These bear strongly on the costs and locations of data-gathering programs. The result has been a wide range of data-collection practices (human vs. automatic, hourly vs. twice-daily, coastal vs. inland vs. offshore, long-term vs. short-term, year-round vs. seasonal, etc.). Although the Atmospheric Environment Service of Environment Canada has the main data-gathering responsibility, other agencies have been active including other components of Environment Canada and other departments such as Energy, Mines and Resources, Transport, Fisheries and Oceans, Indian and Northern Affairs, National Defence, Public Works and National Museums. Supplementing this has been increased private-industry involvement over the past few decades.

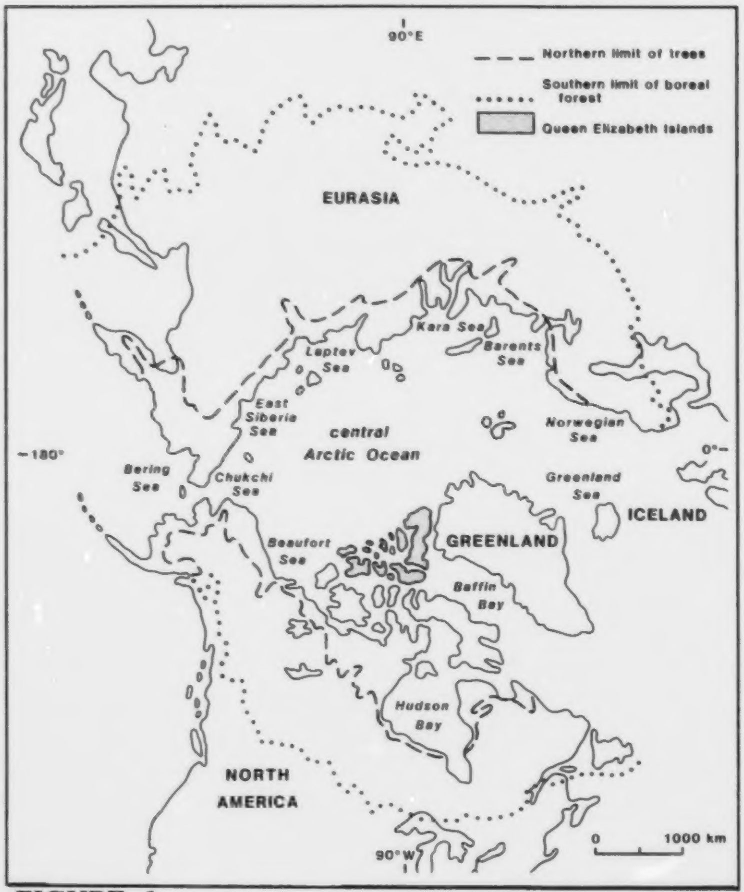

90°E
Northern limit of trees
Southern limit of boreal forest
Queen Elizabeth Islands
EURASIA
Kara Sea
Barents Sea
Laptev Sea
East Siberia Sea
central Arctic Ocean
Norwegian Sea
−180°
0°
Bering Sea
Chukchi Sea
Greenland Sea
ICELAND
Beaufort Sea
GREENLAND
Baffin Bay
Hudson Bay
NORTH AMERICA
90°W
0
1000 km

FIGURE 1: Circumpolar Arctic projection, showing the Queen Elizabeth Islands (shaded) within the Canadian Arctic Islands in relation to the Central Arctic Ocean and peripheral seas.

Climate Database

Climatological data for the QEI are available for a wide variety of locations, but as will be seen, the overall database has important limitations.

AES holds most of the data that are available in one form or another. The stations with the longest and most continuous records are the High Arctic Weather Stations (Alert, Eureka, Isachsen, Mould Bay, Resolute). Originally established in the late 1940s and early 1950s by Canada and the United States, these stations have been in continuous operation since, with the exception of Isachsen which closed in 1978. The duration and continuity of these stations (with the obvious benefits that such records offer for duration and extreme-value analyses) are, however, balanced by the fact that all five are situated at coastal sites. As such, their usefulness for inland or offshore applications may be limited, and any regional climate analysis based solely upon them should be approached with caution.

Other stations in the digital archive include: Craig Harbour, Bache Peninsula, Cape Herschel, Coburg Island, Dundas Harbour, Lake Hazen and Rea Point. These are all coastal locations, with the exception of Lake Hazen, but all are less useful than the High Arctic Stations for various reasons: short period of record, non-continuous record, non-contemporary data, high-elevation or local topographic concerns. Lake Hazen, although it provides the contrast of an inland site, has a continuous record over only one winter plus several summers in the 1950s.

The strong bias towards coastal data in the AES digital archive is balanced somewhat by observations gathered by scientific parties supported by the Polar Continental Shelf Project of Energy, Mines and Resources Canada. A scattering of inland sites is included in this database which is accessible through AES as a separate data-set covering the period 1973-1986. There are drawbacks to these data from the standpoint of length and continuity of record, as well as frequency of observation. For example, a typical station might operate for only one summer or part of the summer at a given location, and take only two observations per day at 12-hourly intervals. They can, however, provide insight into inland conditions, if only for a part of the year. This may be sufficient for certain applications such as vegetation studies. Figure 2 gives an indication of data-coverage during the summer.

While the impetus for the Polar Shelf data collection has been that of interest in related disciplines such as biological and terrain studies, a separate data-set has developed through the activity in the oil and gas exploration sector over the past 15 to 20 years.

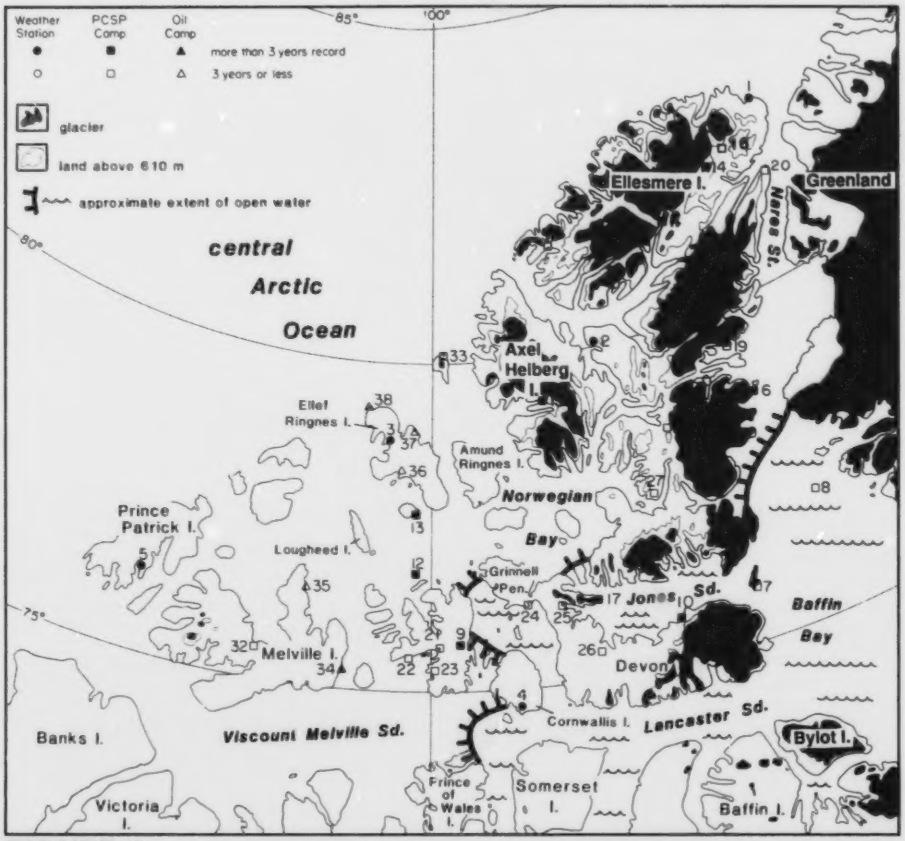

Weather Station
PCSP Camp
Oil Camp
more than 3 years record
3 years or less
glacier
land above 610 m
approximate extent of open water
85°
100°
80°
75°
central Arctic Ocean
Ellesmere I.
Greenland
Nares St.
Axel Heiberg I.
Ellef Ringnes I.
Amund Ringnes I.
Norwegian Bay
Prince Patrick I.
Lougheed I.
Grinnell Pen.
Jones Sd.
Baffin Bay
Melville I.
Devon
Cornwallis I.
Lancaster Sd.
Bylot I.
Banks I.
Viscount Melville Sd.
Prince of Wales I.
Somerset I.
Baffin I.
Victoria I.

FIGURE 2: The Queen Elizabeth Islands: topography, modern glaciers and maximum extent of open water in a typical year (Maxwell 1982). Also shown are **Atmospheric Environment Service permanent weather stations**: 1. Alert, 2. Eureka, 3. Isachsen, 4. Resolute Bay, 5. Mould Bay; **Polar Continental Shelf Project** - supported, short-duration stations: 6. Cape Herschel, 7. Coburg Island, 8. Carey Islands, 9. Polar Bear Pass, 10. Truelove Inlet, 11. Tanquary Fiord, 12. Seymour Island, 13. King Christian Island, 14. Lake Hazen, 15. Expedition Fiord, 16. Piper Pass, 17. Cape Vera, 18. Alexandra Fiord, 19. Princess Marie Bay, 20. Judge Daly Promontory, 21. Bracebridge Inlet, 22. Bradford Island, 23. Hooker Bay, 24. Porden Point, 25. Eidsbotn Fiord, 26. Haughton River, 27. Baumann Fiord, 28. Strathcona Fiord, 29. Neil Peninsula, 30. Irish Arctic Expedition, 31. Clements Markham Inlet, 32. Nias Point, 33. Meighen North; **Oil Industry camps**: 34. Rea Point, 35. Drake Point, 36. Dome Bay, 37. Malloch Dome, 38. Cape Isachsen.

Among the QEI, such activity has included land-based drilling both at land sites and offshore from artificially strengthened ice-platforms during the winter. While these winter offshore data partially fill one gap in the regional climate-data coverage and the summer land-based data further supplement the Polar Shelf observations, the data-set as a whole suffers from its short-term nature: records rarely extend beyond a year at any site.

The QEI offshore area is not well served by climate-data collection programs outside the winter season. There has been increased marine transport activity in connection with the non-renewable resources, but it is usually concentrated in the surrounding waterways, such as the Parry Channel or northwestern Baffin Bay, rather than among the islands themselves. Such data are also available from AES and accessible through MAST as discussed previously.

REGIONAL STUDY

The regional data-analysis presented in the following case study was originally developed to interpret the role played by climate in the observed patterns of plant distribution and diversity (Edlund and Alt 1989). However, it allows inferences to be made concerning other physical and biological environmental characteristics of the region.

The Problem of Scale

Climate and climate change operate on a continuum of time and space scales, from micro to global. It is impossible to separate this continuum into distinct scales; however, in order to address the complex problems of contemporary climatology (including climate change and its impacts on and interactions with the geosphere-biosphere), divisions of this continuum must be attempted. Barry (1970) has proposed distinct scales for the meteorological motion of systems and for spatial systems of climate. Hobbs (1980) tables the European, American and Japanese nomenclature for defining the variable atmosphere. Henderson-Sellers and Robinson (1986) have graphed the time and space scales of various atmospheric phenomena to illustrate the approximate linear relationship between the size of atmospheric features and their time-scales. Scale diagrams developed by Delcourt and Delcourt (1987) in their study of long-term forest dynamics include space and time 'domains' extending back in time to the origin of terrestrial vascular-plant life. Table 2 is a simplified version of the various approaches designed specifically for High-Arctic climate and climatically-sensitive processes.

Each scale of study has its own techniques, applications and problems. When studying climate-geosphere/biosphere interactions, all processes must be considered on the same time and space scale. A number of excellent continuing studies of microclimate and plant environment exist for the QEI (e.g. Courtin and Labine 1977; Freedman *et al.* 1983; Henry

TABLE 2: SCALE.

HORIZONTAL SCALE (KM)	SCALE	TIME SCALE	TOPOGRAPHY (EXAMPLE)	VEGETATION (EXAMPLE)	MINIMUM CLIMATE DATA (EXAMPLE: TEMPERATURE)	EXTENT TO WHICH THESE REQUIREMENTS ARE MET IN QEI
Global to 1000	Global	Decades Years Months	Ocean or continent (Polar Basin)	Ecosystem (tundra)	Surface and upper air grid values	Available on 381 km grid for several time periods
100 to 1000	Regional Synoptic	Months Days	Major topographic feature such as mountain range (intermontane region, Sverdrup Lowlands)	Vegetation zone (Herb Zone[3])	Network of surface and upper-air observations spaced to reflect major regimes	Upper air network adequate; surface network has gaps spatially and temporally
10 to 100	Meso	Days Hours	Valley complex, fiord complex (Truelove or Expedition Fiord study area[1])	Suite of plant communities on a soil catena (Range of plants on alkaline surficial materials through range of moisture)	Series of screen-level temperatures and one upper-air sounding	This type of data only available for limited time periods at specific research sites
1 to 10	Local	Days Hours	Small valley, plain or mountain-side (Oasis[2])	Plant community on one material and moisture regime (sedge meadow[3])	Several screen-level temperatures	As for meso-scale
< or = 1	Micro	Minutes Seconds	Single material or surface-type (beach ridge or snow patch)	Individual plant (Dryas)	Several levels up to screen-level at one site	General not available-particularly for this time scale

[1] Bliss (1977), Ohmura (1981)
[2] Freedman et al. (1983)
[3] Edlund and Alt (1989)

1987; Bergeron 1988). Meso-scale studies have been undertaken largely in conjunction with glaciological projects (Holmgren 1971; Ohmura 1981), although some oasis studies also reach the local scale.

This study focuses on the synoptic or regional scale - the time and space scale of a weather-system that is reflected climatologically by patterns of monthly normals (30 years). It requires a network of surface stations and several upper-air stations to define it properly. (Within the QEI, upper-air station coverage is adequate in this regard; however, at the surface, only four long-term continuous observing stations are operating, and they are all coastal). No comparable inland or offshore observing programs exist. Available data have been previously used (Maxwell 1980, 1982) to describe the region's climate in general terms.

Climate Controls

Climate is controlled by a complex interaction between the radiative energy reaching the top of the atmosphere, the inherent properties of that atmosphere, the motion of the atmosphere (atmospheric circulation), and the large and small-scale characteristics of the earth's surface. In the following case study, these complex climate controls have been approached in the following manner. Atmospheric circulation and its interaction with topography are discussed. The broad features of the solar-radiation regime are then examined and combined with atmospheric circulation to explain the main regional-scale climate patterns in the QEI. The extent to which these patterns can be defined from available data are then discussed.

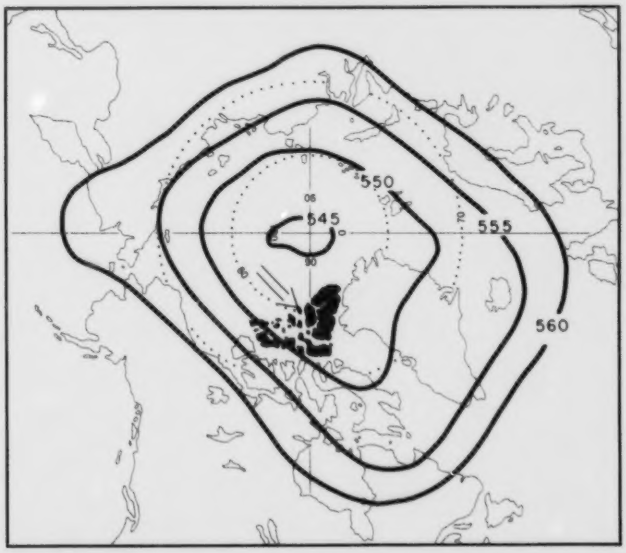


FIGURE 3: **The 1948-1978 mean pattern of July 50-kPa height contours in decametres (dam). From Alt (1987).**

Atmospheric Circulation

The summer atmospheric circulation is shown (Figure 3) by the mean July pressure pattern at 50 kPa (approximately 5,000 m ASL). The 50-kPa circulation is considered the driving or steering-level for surface weather-systems and air-masses. With the exception of the east coasts of Ellesmere and Devon islands, the mean July flow is into the QEI from the central Arctic Ocean. This can also be shown by surface level streamlines which, when calculated from mean flow, show what trajectory a parcel of air would follow. Surface-streamline patterns for June and July (Figure 4) emphasize the predominant northerly or northwesterly movement of air from the central Arctic Ocean over the QEI.

Bryson (1966) pioneered the use of resultant streamlines to define the mean July position of the arctic front and related this to the position of the North American treeline. He also showed the results of tracing trajectories back to four external sources - Arctic, Pacific, and Atlantic oceans, as well as the United States. The frequency of occurrence of arctic air-masses over Canada for July, calculated by the trajectory method, is shown in Figure 5. The QEI lie within the 90% isopleth, and most of the western and central islands lie within the 100% isopleth. Although the results of Bryson's air-mass frequency analysis by the partial collective method (Bryson 1966) suffer from the low density of stations in the QEI, they show similar if less well-defined patterns.

Barry (1967) investigated the location of the continental arctic (cA) front by examining operational frontal-analysis charts for the 85-kPa level (Figure 6). His study showed that in July at 1,500 m over the QEI, an unmodified Ca air-mass occurs at least 80% of the time.

There is thus overwhelming evidence that in June and July, the QEI (with the possible exception of the east coast of Ellesmere and Devon islands) are dominated at all levels by air moving into the islands from the Arctic Ocean.

Topographic Controls

The interaction of the atmosphere and topography takes place at all scales (Table 2). In summer, the season considered here, the central Arctic Ocean is the coldest region of the northern hemisphere with a mean July temperature ranging from -1 to 2.5°C. The surface of the moving polar pack ice is extensively puddled, and this moisture source maintains a nearly continual, low-lying layer of stratus and stratocumulus cloud.

In the northeastern QEI, the mountains of northern Axel Heiberg and northern Ellesmere islands lie athwart the mean circulation, forming a barrier similar to (although not as extensive or as high as) the Cordillera in western North America (Bryson and Hare

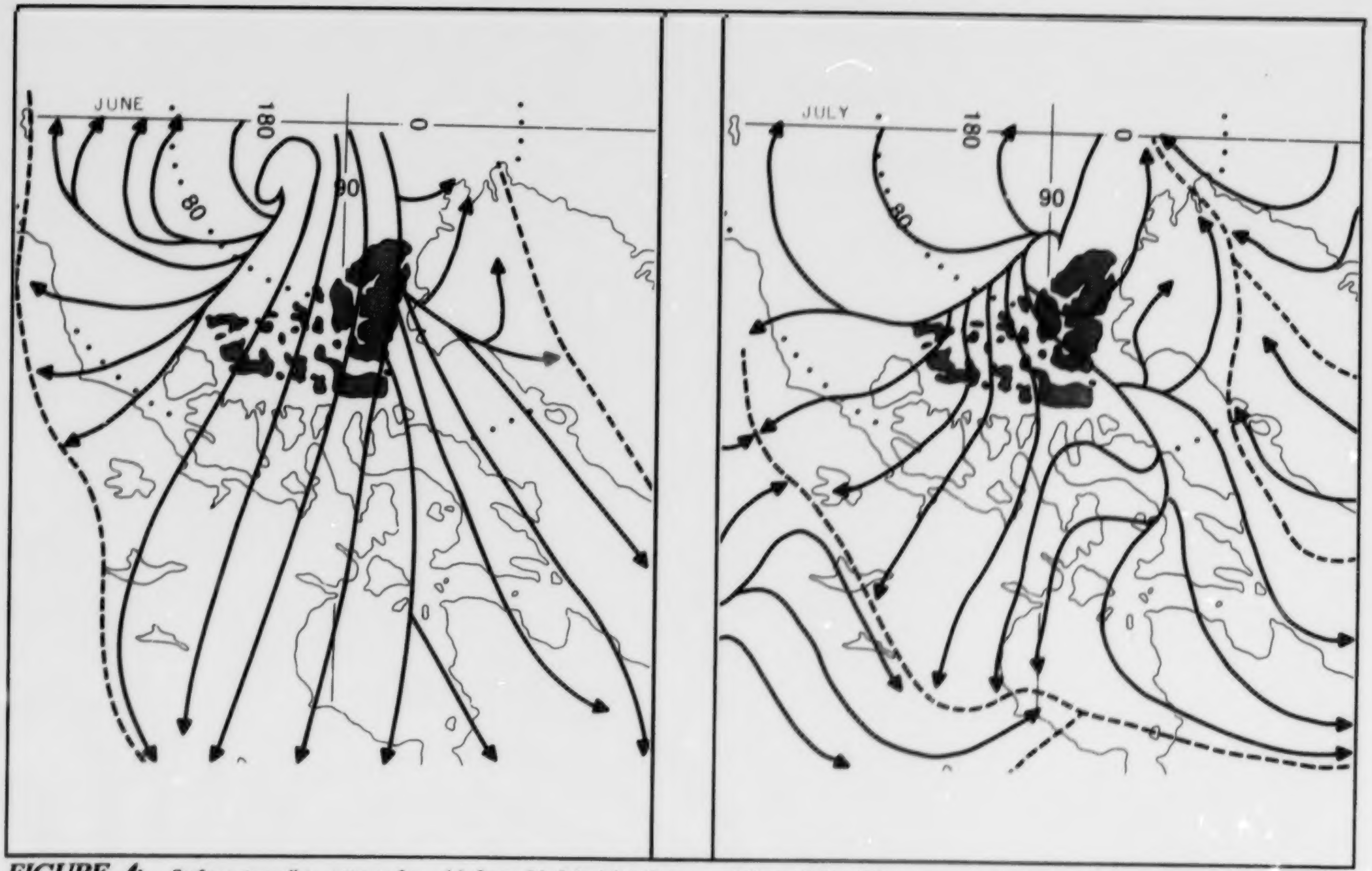

JUNE
180
90
0
80
JULY
180
90
0
80

FIGURE 4: Surface streamline patterns for: (a) June, (b) July (after Bryson and Hare 1974). These represent the trajectories a parcel of air would follow.

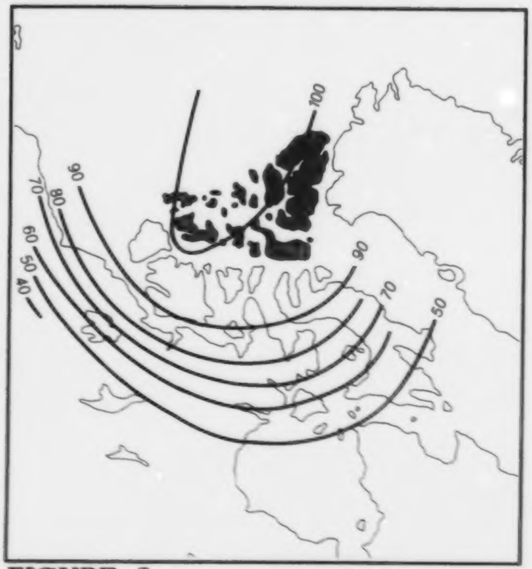

100
90
80
70
60
50
40
90
70
50

FIGURE 5: Frequency (%) of occurrence of air masses of "arctic origin" (after Bryson 1966).

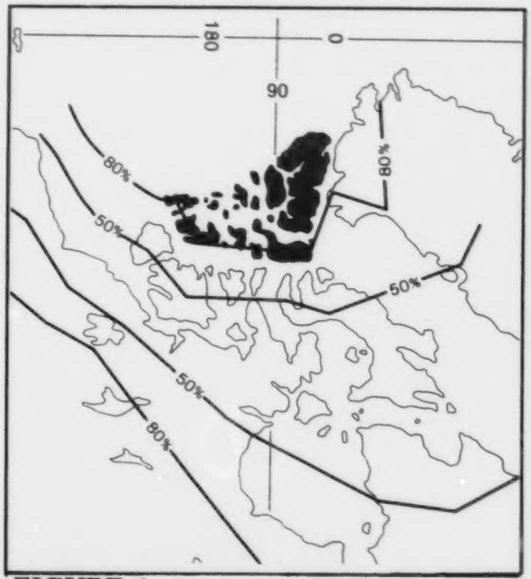

180
0
90
80%
80%
50%
50%
50%
80%

FIGURE 6: Frequency distribution of daily positions of the continental arctic front at the 85-kPa level for July 1961-1965 (modified from Barry 1967). North of the northernmost line, an unmodified arctic air mass occurs in the atmosphere 80% of the time at 1,500 m.

1974). The cold, moist Arctic Ocean air-mass (cA) is either deflected or lifted by the mountains. In the former case, the Arctic Ocean stratus and stratocumulus does not reach the sheltered interior region. In the latter case, the orographically-lifted air cools and precipitates much of its moisture; then it descends the lee-slope of the mountains with warming due to adiabatic compression and with decreasing relative humidity. It arrives in the Eureka Sound area (termed the Eureka Sound intermontane area; Figure 7) with dry, mild characteristics in contrast to the moistness and coldness of the Arctic Ocean air-masses (cA). A similar process of adiabatic-warming due to subsidence affects air entering the region above the central mass of the mountains.

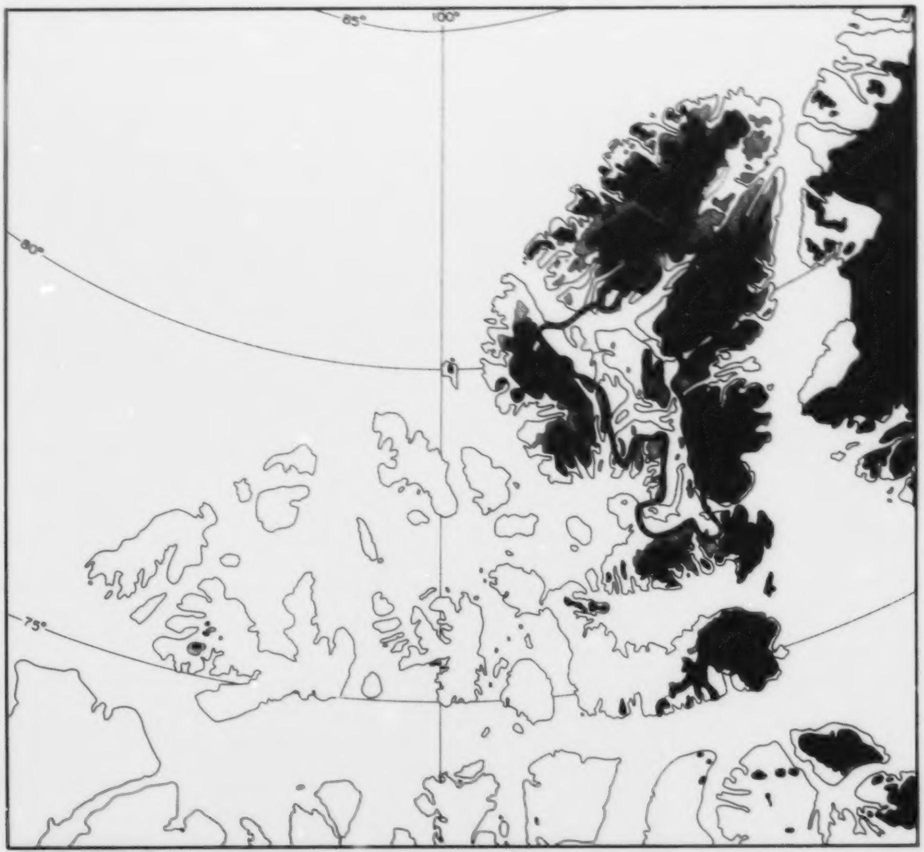


FIGURE 7: **The Eureka Sound intermontane area (heavy outline). The small outlined area in the middle encloses the glacierized mountain ranges of eastern Fosheim Peninsula, which is not strictly speaking an intermontane area. The Sverdrup Lowlands comprise low-lying parts of the central and western QEI.**

These warming processes are observed whenever the prevailing atmospheric flow is forced to cross mountain ranges (Flohn 1969). On a regional scale this results in a belt of precipitation on the windward slope, while the leeward side of the mountains is characterized by dry conditions. At the local scale, intense and sometimes isolated occurrences of warm dry winds in the lee of topographic barriers have been observed globally. These occurrences are often associated with specific synoptic conditions. In the Alps these winds have been known for centuries as 'Foehn'. Similar in effect but differing somewhat in extent and synoptic properties are the 'Chinook' (east of the Rocky Mountains), the 'Zonda' (in the Argentine Andes), and the dry winds in the eastern lowlands of southern New Zealand. The extent, frequency and synoptic nature of such situations in the Eureka intermontane region have yet to be studied, but are doubtless a feature of the area.

Similarly, the Eureka Sound intermontane area is protected from the extensive cloud and fog associated with synoptic systems moving up Baffin Bay and past the Victoria and Albert range to the east and the extensive mountains to the southeast.

This interior intermontane area is a regional-scale feature (Table 2), approximately 400 km long and 120 km wide (Figure 7). In its maximum extent, it is similar in size to the Columbia Basin in the northwestern United States or the Nechuka Plateau between the Coastal Range and the Rockies in British Columbia. Smaller areas on the scale of Alpine valleys (e.g. the Valais area of Switzerland (Wallén 1977)) can also be identified.

Distinct from the intermontane area, the central and western QEI experience cA air, which penetrates deeply the Sverdrup Lowlands. Over the sea ice of the inter-island channels, the air-mass undergoes little modification. The ice-bound islands of the Sverdrup Lowlands produce only local and meso-scale orographic uplift. This, coupled with the low stratus-stratocumulus cloud deck from the Arctic Ocean, results in frequent fog and low ceilings along exposed coasts. Inland, local and meso-scale thermal modification occurs through a shallow layer of the atmosphere. At times, the modification is deep enough to burn off the low-level cloud. The synoptic-scale nature of the air-mass remains, however, essentially unchanged.

Solar Radiation Regime

Solar radiation provides the energy to run the atmosphere. Unfortunately, observations of solar radiation and of radiation-balance in the Arctic Islands are sparse, records often being broken and of short duration. The observations that do exist suffer from a number of serious problems (Holmgren 1971; Dahlgren 1974; Maxwell 1980; Ohmura 1981). Published normals from the five AES stations do not adequately represent the relative values for these stations as there are missing years in the record. For example, there are only three years of simultaneous July records for all stations during the 1951-1980 normal period. Calculations of the radiation components, such as those of Vowinckel and Orvig (1962) or those used by McKay and Morris (1985), depend on the accuracy of the model and require accurate measurements for calibration. The values given in Table 3, however, allow a few important generalities to be made regarding the summer radiation regime of the QEI.

TABLE 3: JULY MEAN DAILY SOLAR RADIATION COMPONENTS.

STATION	Global Radiation ($MJm^{-2}d^{-1}$)				Surface Albedo Measured (Estimated)	Global Radiation Absorbed ($MJm^{-2}d^{-1}$)			
	From Measured Values			Calculated Values		From Measured Values			Calculated Values
	Average of 1971, 1972 and 1977[1]	Published Normals[2] (No. of Years)	Specific Years			Average of 1971, 1972 and 1977[1]	Published Normals[2]	Specific Years (Year)	
Resolute Bay	19.0	18.7 (23)	16.4 (69,70)	18.0[4]	.39[2]	11.6	11.6	10.0 (69,70)	11.0
Resolute Bay			16.3 (73)					10.0 (73)	
Resolute Bay			16.9 (74)					10.3 (74)	
Eureka	19.4	18.8 (11)	18.6 (80-84)		(.15)	16.5	16.0	15.8 (80-84)	
Alert	18.4	18.8 (16)		18.4[4]	(.15)	15.6	16.0		15.6
Isachsen	16.5	16.9 (8)		17.7[4]	(.45)	9.1	9.3		9.7
Mould Bay	18.5	17.4		19.7[3]	(.45)	10.2	9.6		10.8
80 N 100 W				22.1[3]	.45[3]				19.9
80 N 80 W				18.6[3]	.45[3]				10.3
75 N 100 W					.45[3] (.10)[8]				
Expedition Fiord			15.4 (69,70)[5]		.10[5]			13.9	
Devon Base			18.8 (61,62)[6]		.15[5]			16.0	
Coburg Island			22.6 (73,74)[7]		.13[7]			19.7	
Carey Islands			18.5 (74)[7]		.13[7]			16.1	
Alexandra Fiord			19.4 (80-84)[9]		(.15)			16.4	
Thule AFB		20.5			(.15)		17.4		
Edmonton		21.9 (14)			.17		18.1		

[1] The only three years of simultaneous records at QEI stations for July were 1971, 1972 and 1977.
[2] Atmospheric Environment Service 1982.
[3] Vowinckel and Orvig 1962.
[4] McKay and Morris 1985.
[5] Ohmura 1981.
[6] Dahlgren 1974.
[7] Muller et al. 1975.
[8] Albedo estimated for land areas such as Fosheim Peninsula, not including ice caps.
[9] Henry 1987.

In May, June and July, solar radiation reaching the top of the atmosphere at 80°N is greater than at any lower latitude, owing to the 24 hours of daylight. Radiation reaching the ground (global radiation) is strongly dependent on cloudiness. Under clear-sky conditions, the global radiation received at 80°N is greater than that received at 70°N along the mainland coast. Average global radiation values from permanent weather stations in the QEI for July 1971, 1972 and 1977 (the three years of simultaneous July records mentioned above) show a maximum at Eureka and a minimum at Isachsen (Table 3). The calculations of Vowinckel and Orvig (1962) show a minimum of global radiation west of Mould Bay and Isachsen over the Arctic Ocean. Though the actual magnitude of the difference in incoming global radiation between the Sverdrup Lowlands and the Eureka Sound intermontane area cannot be established due to instrument and missing-data problems, it is important to note that it is of the same order as the difference between Vancouver and interior British Columbia.

The reflective property (albedo) of the surface determines how much global radiation is actually absorbed by the ground. Measurements of surface albedo (Table 3) are available for Resolute and several expedition sites (Holmgren 1971; Dahlgren 1974; Alt 1975; Müller *et al.* 1976; Courtin and Labine 1977; Ohmura 1981). The following generalizations regarding regional albedo can be made.

Snow remains on the ground throughout June in the central and western QEI and at high elevations in the mountains of Ellesmere and Axel Heiberg islands. Thus, these regions have a high albedo. At Expedition Fiord and in other interior valleys of western Axel Heiberg Island, snow disappears by mid-June (Ohmura 1981). Snow disappears even earlier in the Eureka Sound intermontane area. Thus, the low albedos in June enhance the total energy absorbed in the interior area, while high albedos reduce the absorption of available energy over the sea ice and snow-covered areas in the northwestern portion of the islands.

By July, most of the land in the QEI is snow-free. Albedo differences between the Eureka Sound intermontane area and the Sverdrup Lowlands are less pronounced; however, differences in the surficial materials, vegetation-cover and moisture-content of the ground still result in enhanced absorption in the intermontane region and reduced absorption in the exposed lowlands.

In both months, therefore, the gradient of solar radiation absorbed at the ground is not latitudinal. Rather, the highest values are in the interior of Ellesmere and Axel Heiberg islands, and the lowest values west of Isachsen and Mould Bay over the pack ice of the central Arctic Ocean.

Summer Climate Patterns

Introduction

To examine how the distinctive climate regions produced by the interaction of solar radiation, general circulation and topography are reflected in regional summer patterns of temperature and precipitation, it is necessary to construct regional patterns of these parameters. In the QEI, this task is complicated by two serious problems: (1) the lack of adequate long-term stations and the representativeness of the existing stations; and (2) the complex mosaic of surface-conditions occurring in the islands. Surface-conditions within the islands and adjacent waters include: snow-covered mountains, ice caps, valley glaciers, snow-free rocks, bare ground, well-vegetated terrain, sea ice and open water. Several of these features often occur within a few square kilometres. So it is impossible to draw definitive maps of regional-scale parameters. However, in response to the needs of regional-vegetation studies (Edlund 1986) and to other studies of the physical and biological environment, we present regional maps of selected summer-climate parameters in as much detail as the data allow and in a form that meets the needs of regional-distribution studies. See Maxwell (1980, 1982) for comprehensive traditional treatment of the climate of this region.

Lower Troposphere

The interaction of circulation and topography is clearly portrayed in the mean June and July cloud-charts (Figure 8a,b). The prevailing northwesterly tropospheric flow drives the extensive stratus and stratocumulus cloud from the central Arctic Ocean into the Sverdrup Lowlands. Over the Eureka Sound intermontane region mean cloud amounts are 20% lower than over coastal areas bordering the polar pack. The satellite photograph (Figure 9) shows a typical example of these cloud conditions.

The same factors are apparent in the distribution of lower-troposphere temperatures as shown by July 90-kPa temperatures (Figure 10). Topography was not taken into account

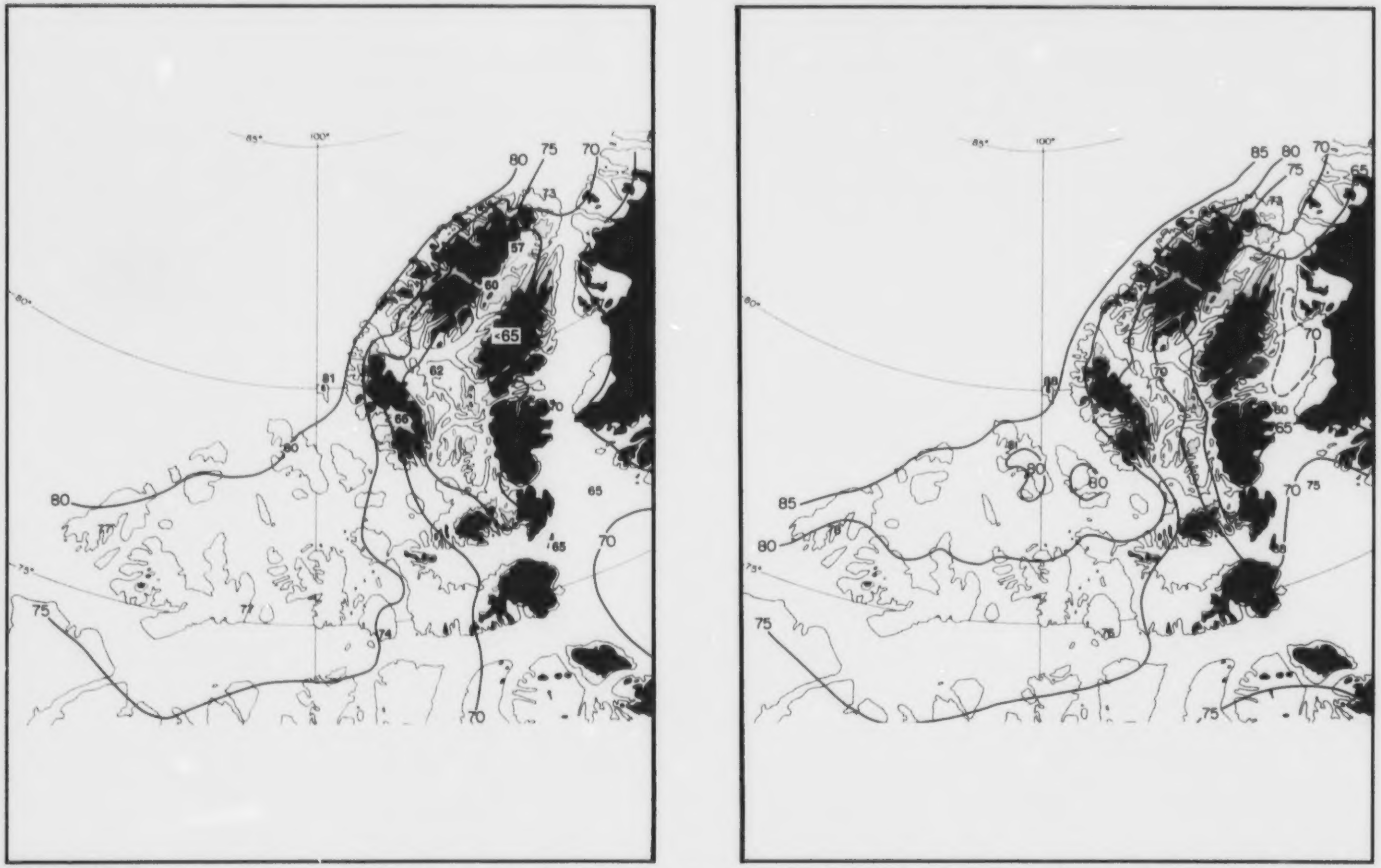

85°
100°
80°
75°
80
75
70
73
57
60
<65
62
81
66
70
80
65
70
65
77
74
77
75
70
85
80
70
75
65
73
70
70
80
65
80
80
70
75
68
78
75
85
80
78
75
75

FIGURE 8: Mean cloud-cover (%) for (a) June and (b) July based on the period 1959-1979. Where applicable, field-station data were used (corrected as discussed in caption for Figure 11).

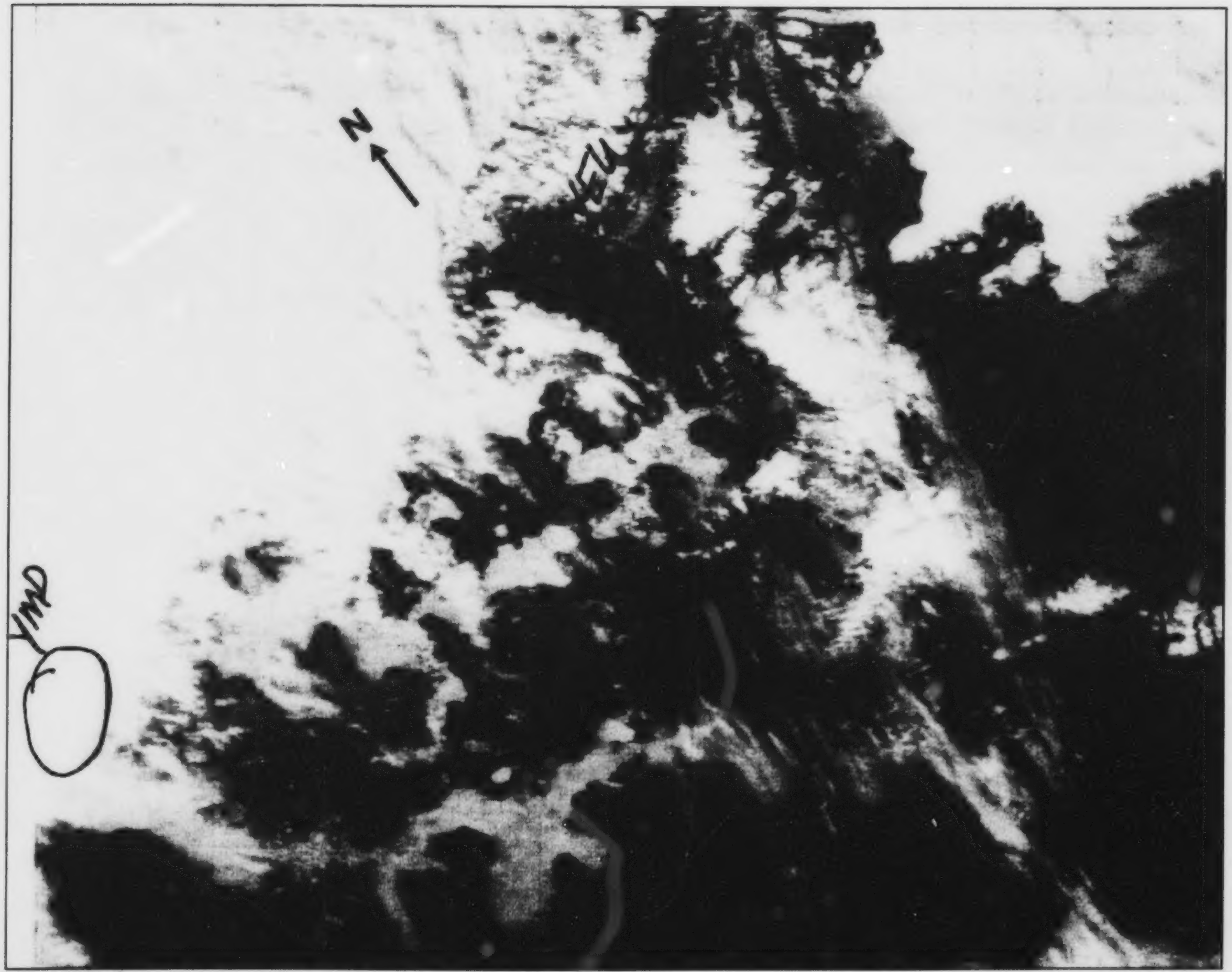


FIGURE 9: A typical example of cloud conditions over the Queen Elizabeth Islands during northwesterly flow. Image received by Geological Survey of Canada at Resolute from the Soviet METEOR weather satellite. Approximate positions of Mould Bay ("YMB"), Resolute ("YRB"), Eureka ("YEU") and Igaluit ("YIQ") have been marked.

when drawing the contours. These were spaced and shaped as demanded by the values of the five data-points alone. The intrusion of cold Arctic Ocean (cA) air over the Sverdrup Lowlands and the sheltering effect of the mountain barriers in the east form an S-shaped pattern similar to the cloud-patterns. This general S-shaped pattern is thus a macro or synoptic-scale phenomenon, reaching at least 1,000 m into the atmosphere and reflecting the impact of regional-scale topography on the lower troposphere.

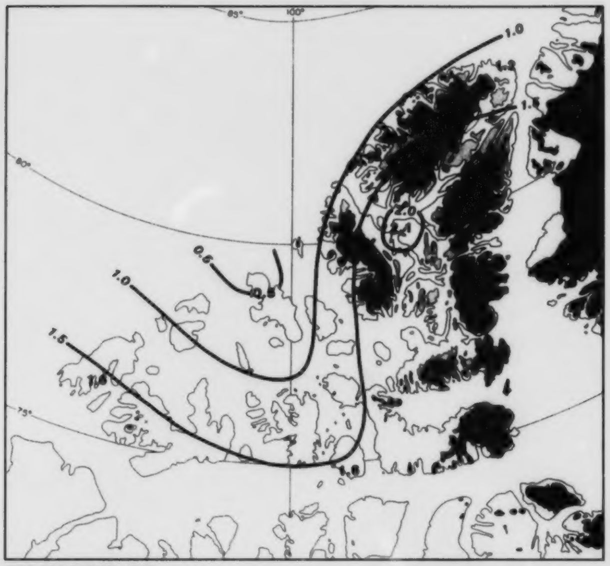


FIGURE 10: Mean July temperature at 90 kPa (ca. 1,000 m) for 1951-1980.

Temperature

The sparse surface-data network was augmented by incorporating information from seasonal scientific and oil-industry camps (Figure 2). Only stations for which a whole month (July) of daily mean records existed were used. Each monthly mean value for each year was adjusted to represented a 1951-1980 normal. The deviation from the 30-year normal at the closest permanent station(s) was used to adjust the monthly mean values from each field station. Values for the individual years were then averaged, resulting in a 30-year normal equivalent value. This method must be considered a first approximation as it neglects some important items, such as the fact that the normal period used was 1951-1980, while many of the years with data were in the 1980s.

Even with the addition of the field-station data (Figure 11), the interiors of the islands are virtually unrepresented. This is also true of the stations in the Eureka Sound intermontane area, most of which are on fiords or lakes. This problem has been used to advantage by plotting sea-level maps of both temperature and precipitation. The contours have been drawn through sea-level coastal station values. For any contour there are a range of values. For instance, in summer the lowest values would be found over the ice-bound channels and the highest at sheltered interior sites. Inland contours have been drawn only when they represent regional-scale features (i.e. 100 km or greater in size). Contours

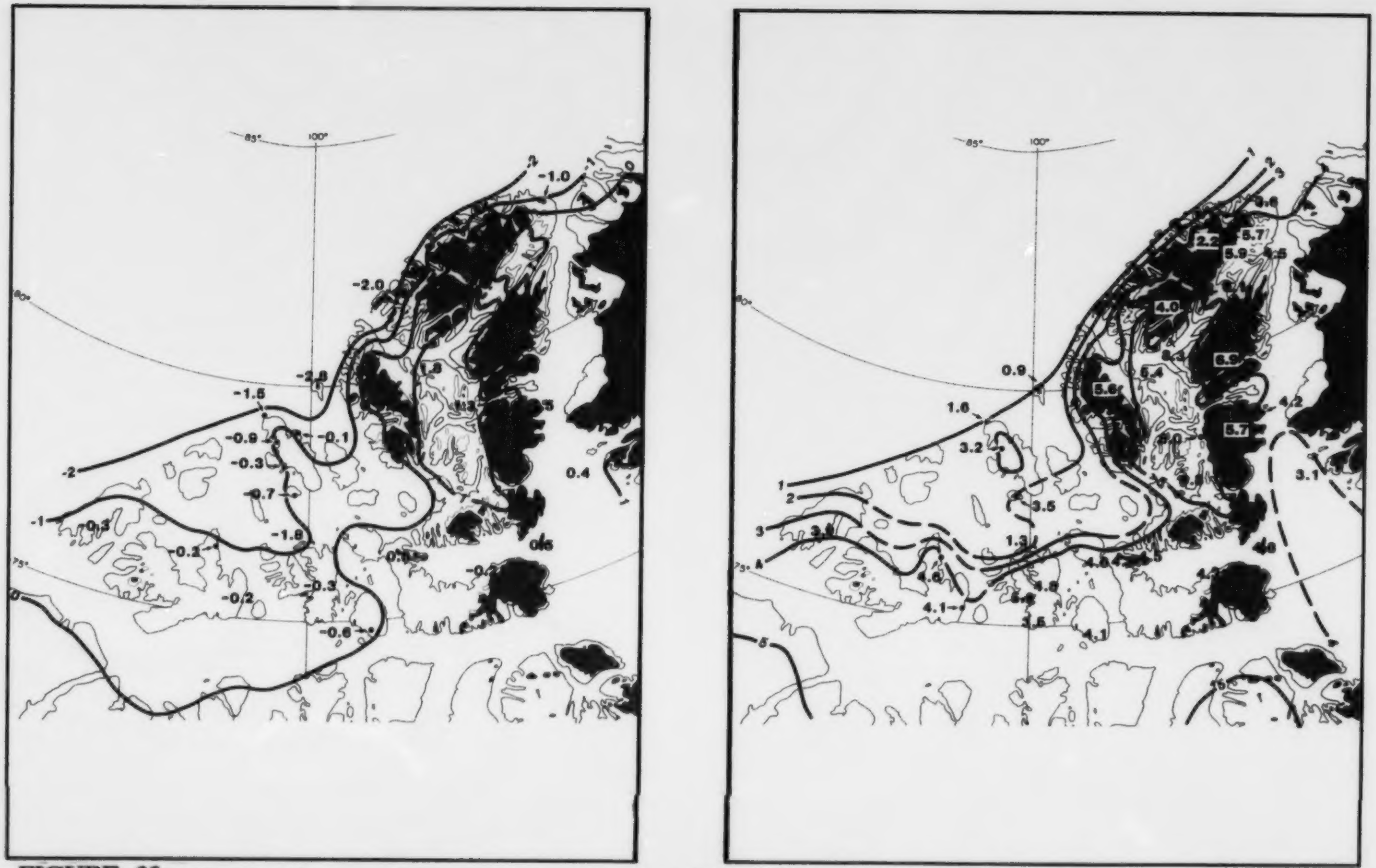

85°
100°
80°
75°
-1.0
-2.0
-2.8
-1.5
-0.9
-0.1
-0.3
-0.7
-1.8
-0.3
-0.2
-0.2
-0.3
-0.6
0.4
-2
-1
0
0.9
1.6
3.2
3.5
1.3
2.2
5.7
5.9
4.0
6.9
5.6
5.4
5.7
4.2
3.1
4.1
3.6
1
2
3
4
5

FIGURE 11: Mean monthly summer temperatures (°C) over the Queen Elizabeth Islands for: (a) June, (b) July. Permanent weather stations and non-standard weather data were used. Correction factors, developed through comparison with the appropriate permanent weather station records, were applied to the short-term record to produce values for the 1951-1980 normal period.

have not been drawn in mountainous areas (over 600 m, light-shading on maps) or over ice caps (shaded on maps). In drawing details of the contours, consideration was given to common sea-ice patterns and boundaries.

July (Figure 11b) temperatures at 80°N over the Sverdrup Lowlands are 4°C colder than similar coastal stations in the Eureka Sound intermontane area, whereas in June (Figure 11a) the 0°C isotherm separates the two areas. A relatively steep temperature-gradient exists over northern Ellesmere and Axel Heiberg islands which broadens in the Sverdrup Lowlands as the cA air-masses are gradually modified by increasing exposure of land.

In the intermontane area, coastal temperatures in July are greater than 5°C. Indications are that, inland, the temperatures are considerably warmer, although accurate long-term data are not yet available. Several field projects, begun in 1988, will eventually provide an accurate quantitative evaluation of inland temperatures.

In the Sverdrup Lowlands (Figure 7), the Isachsen and King Christian Island (KCI) (Figure 2) temperatures seem higher than those from other coastal stations. In the case of Isachsen, the site is somewhat sheltered. The KCI temperatures cause a sharp bend in the 2°C isotherm. This may reflect the generally less severe sea-ice conditions to the southeast of the island, or it may be due to the siting of the camp or the height at which temperatures were measured. (For instance, one of the July means from this station had to be dropped, as the station description noted that the screen was located at ground-level.) This emphasizes the care with which field-station data must be handled.

Although the Sverdrup Lowlands and Eureka intermontane areas provide the greatest contrast in sea-level climate within the QEI, several other distinctive regions exist, such as the northeastern corner of Ellesmere Island and the area surrounding the North Water and northern Baffin Bay. They too should be integrated into future regional-scale studies.

Though it is necessary to increase the surface-data coverage, especially inland where accurate long-term climate stations are lacking, and to strive for long-term accurate data, greater use can be made of the existing records. Incorporation of oil-camp data is a first step. The coverage can also be considerably increased by constructing maps of 00Z and 12Z temperature from the morning and evening Polar Shelf field-station data. These can then be compared to the daily mean temperature maps, thus providing valuable information in some critical areas. Evaluation of the magnitude of the errors associated with the various types of data is also needed.

The details of the temperature-patterns will undoubtedly change with the addition of new stations and more comprehensive techniques for using field-station data; however, this will not alter the S-shape or general features of the present synoptic-scale climate configuration. Strong interannual variations do occur, though, and the pattern may be amplified or reversed seasonally, and may alter with long-term climate change.

Precipitation

Precipitation measurements in the Arctic are subject to serious inaccuracies. Winter snow-accumulation values from the permanent weather stations appear to be underestimated by 40 to 400% (Koerner 1979; Maxwell 1980; Woo *et al.* 1983).

Mean total annual precipitation, mean total summer precipitation and mean snow-depth on 31 January have been plotted (Figure 12a,b). Areas over 600 m or covered by ice caps were ignored, to be consistent with the regional (near sea level) temperature analysis.

Total annual (Figure 12b) and summer precipitation (Figure 12a) and winter snow-depth (Figure 12a) values all show similar distributions. The highest precipitation occurs in the area under the direct influence of the North Water and Baffin Bay cyclone. A secondary maximum is found to windward of the mountain barriers on northern Ellesmere and Axel Heiberg islands. Precipitation minimums occur in the Eureka Sound intermontane region due to the precipitation-shadow effect, and in the far western islands due to the proximity of the persistent surface anticyclone.

Precipitation amounts, thus, do not produce the same S-shaped pattern as seen in the temperature analyses. This indicates that at a regional scale they are controlled by a different mechanism. Previous studies have also suggested that the major control on precipitation is the frequency and intensity of cyclonic activity, and that the interaction of topography and mean atmospheric flow is secondary (Müller *et al.* 1976; Maxwell 1980; Bradley and Eischeid 1985). Considerably more study of the synoptic situations responsible for extreme and significant precipitation events is necessary, not only to determine the regional patterns and their effects, but also to establish source regions for the moisture, pollen and aerosols composing that precipitation.

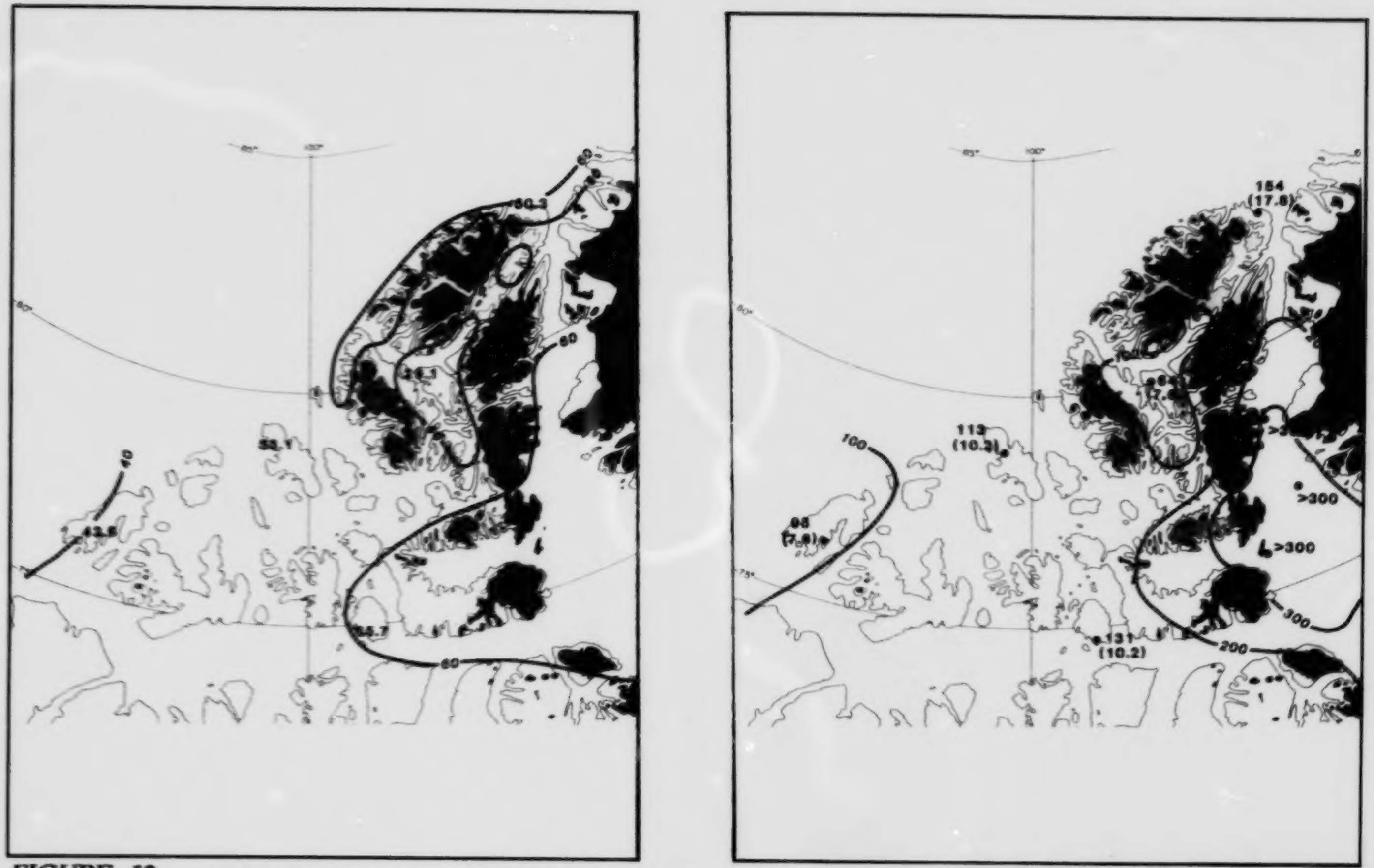

85°
100°
80°
75°
60
50.3
60
34.1
53.1
40
43.6
55.7
60
154
(17.8)
100
113
(10.3)
98
(7.6)
>300
>300
300
200
131
(10.2)

FIGURE 12: (a) Mean total summer (June, July and August) precipitation in mm (contoured) for the Queen Elizabeth Islands; (b) Mean total annual precipitation (mm) and snow-depth at the end of January in cm (in brackets)

SUMMARY

Implications of Regional-Study Results

The prevailing atmospheric flow into the Queen Elizabeth Islands comes from the area of radiation minimum - the area where least heat is available. Air-masses which have their source here have been cooled by the vast expanse of the central Arctic Ocean pack ice. The topography of the QEI modifies the radiation and general circulation-patterns producing several distinctive regions. In the Sverdrup Lowlands, an incoming radiation minimum combines with a cold advection maximum. In the intermontane regions of Axel Heiberg and Ellesmere islands, a radiation maximum combines with a minimum of cold-air advection.

The resulting regional climatic contrasts are reflected in distributions within the biosphere and geosphere. Edlund and Alt (1989) concluded that regional-vegetation patterns respond strongly to these controls. Vegetation in the Eureka Sound intermontane area rivals that on southern Victoria Island, while the Sverdrup Lowlands climate produces Beschel's (1969) "Barren Wedge". The inter-island channels within the Sverdrup Lowland remain ice-covered all summer in contrast to Eureka Sound which is navigable in all but the most severe seasons. Mass-balance regimes of glaciers and ice caps exposed to the central Arctic Ocean are characterized by low summer melt-values and the occurrence of summer accumulation (Alt 1975, 1987). Within the Eureka Sound intermontane area outlet glaciers are subject to considerably more summer melt resulting in elevated equilibrium lines (Hattersley-Smith 1969).

Paleoenvironmental records from the two distinct areas would be expected to indicate differing climatic conditions and responses. The specific nature of the differences would depend on the circulation and surface-conditions prevailing at earlier times. Similarly, the effect of future climate and environmental changes would not necessarily be uniform across the QEI, depending on the specific nature of those changes and their synoptic-scale effects. Future interactive studies of environmental change will need, in addition to a more complete database, detailed analysis of the synoptic situations associated with regional patterns and anomalies.

Gaps

A glance at any surface-weather map showing the observing stations in existence in the Canadian Arctic in general, or in the QEI specifically, will convey clearly the problems of representativeness that need to be overcome. Many of these have also been illustrated by the results of this QEI case study. The problems relate to geographical coverage, surface-conditions, inter- and intra-annual continuity, observational frequency and uniformity in terms of elements observed and instrumentation used.

There are many obvious blanks in geographical coverage. The Viscount Melville Sound area is a large one. In the QEI, since the closing of Isachsen in 1978, the entire Sverdrup Lowlands has no station in the observing network whatsoever, and problems such as the seemingly warm area around King Christian Island cannot be resolved given present data-coverage. The southern Ellesmere-Devon island region is similarly unrepresented, including the Canadian side of the North Water.

As mentioned earlier, the Canadian Arctic Islands present a complex mosaic of differing surface-conditions. Such a region requires a much denser coverage of observing sites to allow a thorough characterization of the climate than would a region with more uniform conditions. Unfortunately, in the Arctic Islands, station density is lower than that of more uniform regions of Canada. This problem is compounded by the almost exclusively coastal location of stations. Inland and offshore areas are only represented by short-term data-programs.

Looking at maps of station sites can be deceptive in several ways beyond the obvious problems of geographical coverage and surface representativeness. For example, a map showing all climate-observing stations active within the QEI since 1972 would suggest an impressively thorough coverage. It would include some 200 Polar Shelf-supported sites, about 60 Panarctic sites, as well six AES network stations. The Polar Shelf stations are the only ones including inland sites (however, they are only operational in summer and in most cases for limited parts of that season). Additionally, many stations have been in existence for only one summer. The Panarctic sites include both onshore and offshore locations, but data from the latter are restricted to winter observations taken at on-ice installations. Like the Polar Shelf stations, Panarctic activities tend not to last more than a year or so at any given site. Only the AES stations offer operational continuity, although Isachsen's record ends in 1978. However, the exclusively coastal siting of AES stations must be considered.

As a result, for evaluating July mean temperature, only the six AES stations offered long-term continuous records. About 30 of the 200 Polar Shelf and 12 of the 60 Panarctic stations (although the latter were not used) provided July values for various individual years; less than a third of these have more than a one-year record. This resulted in considerable station-by-station evaluation and adjustment - highly subjective at times.

The other aspect of data-usefulness not apparent from simple station lists or maps is the frequency with which observations are taken each day. Statistics based on observations taken twice daily can be significantly different from those of hourly observations. Such disparities in frequency are common for the various stations from which data are collected in the Arctic Islands, and they occur not only between networks of stations operated by different agencies, but also within such networks. Improved analytical techniques must be developed to handle such data.

The range of climatic elements observed at any station can also vary considerably. The problem is not so great with the basic elements such as temperature, wind, pressure, visibility, etc., but with the more specialized ones such as radiation, snowcover, soil-temperature and the like. Of course, the generally greater complexity and cost of the necessary instrumentation is a factor. Though the problem is far from being exclusively an arctic one, the remoteness of the area adds substantially to the cost. The difficulties of trying to evaluate areal patterns when coverage is incomplete spatially and incompatible temporally are apparent from the discussion of radiation in this QEI case study.

Ways to overcome these gaps are not simple. We cannot merely set up conventional, manned stations wherever they are needed, because the costs involved are prohibitive. Less expensive data-gathering alternatives must be found. More advantage must also be taken of existing capabilities and developing technologies, and greater use must be made of data already available.

These approaches are now being increasingly recognized and applied. For example, the work of Edlund and Alt (1989) and this paper represent the first broad use of the Polar Shelf climate data-set, although individual station-data have contributed to a number of studies. The results of this case study suggests the greater potential, not only of the Polar Shelf data, but also of other non-AES sources such as the oil industry (Panarctic data from the QEI and the Dome/Gulf Beaufort drilling), the Arctic Buoy Program in the Arctic Basin, ice-island data, and gridded surface and upper-air data-sets available through the

United States. Even the AES network station data are not fully exploited; fields such as cloud, radiation, snowcover, etc. offer useful opportunities. With the data that are already available, then, it is important to recognize the deficiencies. But, having done that, it is essential to examine how such data can be applied directly, or made more useful through appropriate comparisons with other data or through calibrations with physical variables related to sea ice, permafrost and glaciers (for example) which will allow extending or improving existing records.

A method of obtaining new data that has become increasingly feasible in the Arctic Islands with advances in technology is the use of automatic remote climate stations. Such an installation equipped to record air-temperature, shallow soil-temperature, wind-speed and direction, humidity, radiation, and snow-depth and capable of untended year-round operation, costs in the order of $10,000 to $15,000 depending on the particular sensor-configuration. Data are stored in electronic-memory modules that can be accessed as required. It is desirable to visit such installations annually, but as they are usually established in conjunction with programs where climate is only one component, the annual visit can be timed to fit other field activities so that no additional cost is incurred. Examples are the interdisciplinary programs at Hot Weather Creek on Fosheim Peninsula, Ellesmere Island (Edlund *et al.* 1989) and at Amadjuak and Nettilling lakes on Baffin Island (Jacobs *et al.*, this volume). An important concern as such installations become more prevalent is standardization of instrumentation, climate elements observed, and observing frequencies. Uniformity here will facilitate data-comparison and easy application of analysis-programs and systems.

Satellites have the potential to provide, at least on a regional scale, some of the climate and climate-related information that is so difficult and expensive to acquire using conventional methods. An advantage of this approach is the continuous rather than discrete areal sampling that is possible. This is a distinct benefit among the Arctic Islands with its varied surface-characteristics. Useful data can be obtained for such climate and related elements as air-temperature, winds, waves, cloud, snowcover and sea ice. Microwave technology, for example, is beginning to show considerable potential for sea-ice studies, particularly in respect to sea-ice type (age) definition and details of ice-extent. The U.S. Defense Meteorological Satellite Program using the recently launched Special Sensor Microwave Imager (SSM/I) offers the best opportunity yet for routine, daily, all-weather sea-ice coverage in near real time. A data-processing and management system making the resulting data available to the research community is being developed by several interested U.S. agencies.

Our understanding of the climate of the Canadian Arctic Islands is still, in many ways, incomplete. We have tried to show why that is so, particularly in one specific geographical area of the islands. In so doing, it has been possible to suggest some general measures by which our understanding could be improved. The high level of interest in the Canadian Arctic Islands which continues to be reflected in the extensive field research programs being undertaken each year, as well as the developing global-change issue, provides hope that such measures will be pursued.

ACKNOWLEDGEMENTS

We would like to acknowledge all the individuals and agencies who were instrumental in collecting the climate data used in this paper. The case study owes its existence to the persistence of Dr. S. Edlund of the Terrain Sciences Division, Geological Survey of Canada.

REFERENCES

Addison, P.A. and L.C. Bliss. 1980. Summer climate, microclimate and energy budget of a polar semi-desert on King Christian Island, N.W.T., Canada. Arctic and Alpine Research 12(1):161-170.

Alt, B.T. 1975. The energy balance climate of Meighen Ice Cap, N.W.T. 2 Volumes, Energy, Mines and Resources, Canada. Polar Continental Shelf Project, Monograph 67:1-67;1-101.

______. 1987. Developing synoptic analogs for extreme mass balance conditions on Queen Elizabeth Island ice caps. Journal of Climate and Applied Meteorology 26(12):1605-1623.

Atmospheric Environment Service. 1981. Climatological station data catalogue. The North - Y.T., N.W.T. Environment Canada, Downsview, Ontario. 33 pp.

______. 1982. Canadian climate normals. Volume 1. Solar radiation 1951-1980. Environment Canada, Downsview, Ontario. 57 pp.

Barry, R.G. 1967. Seasonal location of the arctic front over North America. Geographical Bulletin 9(2):79-95.

______. 1970. A framework for climatological research with particular reference to scale concepts. Institute of British Geographers, Transactions No. 49:61-70.

Bergeron, J-F. 1988. Plant communities of Sverdrup Pass, N.W.T. Unpublished M.Sc. thesis, University of Toronto, Toronto, Ontario.

Beschel, R.E. 1969. Floristicheskie sootnosheniyz na ostrovakh Neoarktiki. (Floristic relations of the Nearctic Islands. Canada, Secretary of State translation.) Botanicheski Xhurnal 54(6):872-891.

Bliss, L.C. (editor). 1977. Truelove Lowland, Devon Island, Canada: a High Arctic ecosystem. University of Alberta Press, Edmonton, Alberta. 714 pp.

Bradley, R.S. and J.K. Eischeid. 1985. Aspects of the precipitation climatology of the Canadian High Arctic. In: Glacial Geologic and Glacio-climatic Studies in the Canadian High Arctic. Edited by: R.S. Bradley. University of Massachusetts, Amherst, Contribution No. 49:250-271.

Bryson, R.A. 1966. Air masses, streamlines and the boreal forest. Geographical Bulletin 8(3):228-269.

Bryson, R.A. and F.K. Hare. (editors). 1974. Climates of North America. World Surveys of Climatology. Volume 11. Elsevier, Amsterdam. 420 pp.

Courtin, G.M. and C. Labine. 1977. Microclimatological studies on Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: a High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 73-106.

Dahlgren, L. 1974. Solar radiation climate near sea level in the Canadian Arctic Archipelago. Arctic Institute of North America Devon Island Expedition 1961-62. Meterologiska Institutionen Uppsala Universitetet Meddeleleser No. 121:1-119.

Delcourt, P.A. and H.R. Delcourt. 1987. Long-term forest dynamics of the temperate zone: a case study of Late-Quaternary forests in eastern North America. Springer-Verlag, New York.

Edlund, S.A. 1986. Modern arctic vegetation distribution and its congruence with summer climate patterns. In: Proceedings, Impact of Climate Change on the Canadian Arctic (Orillia, Ontario, March 3-5, 1986). Edited by: H.M. French. Atmospheric Environment Service, Downsview, Ontario. pp. 84-99.

Edlund, S.A. and B.T. Alt. (1989). Regional congruence of vegetation and summer climate patterns in the Queen Elizabeth Islands, Northwest Territories, Canada. Arctic 42(1):3-23).

Edlund, S.A., B.T. Alt, and K. Young. 1989. Vegetation, hydrology and climate at Hot Weather Creek, Ellesmere Island, Northwest Territories. Climatic Fluctuations and Man 4:65.

Flohn, H. 1969. General climatology, 2. World survey of climatology, Volume 2, Elsevier, Amsterdam. 270 pp.

Freedman, B., J. Svoboda, C. Labine, M. Muc, G. Henry, M. Nams, J. Stewart, and E. Woodley. 1983. Physical and ecological characteristics of Alexandra Fiord, a High Arctic oasis on Ellesmere Island, Canada. In: Proceedings, 4th International Conference on Permafrost, Fairbanks, Alaska. pp. 301-306.

Hattersley-Smith, G. 1969. Glacial features of Tanquary Fiord and adjoining areas of northern Ellesmere Island, N.W.T. Journal of Glaciology 8(52):23-50.

Henderson-Sellers, A. and P.J. Robinson. 1986. Contemporary climatology. Longman S&T, Harlow, England. 439 pp.

Henry, G.H.R. 1987. Ecology of sedge meadow communities of a polar desert oasis: Alexandra Fiord, Ellesmere Island, Canada. Unpublished Ph.D. thesis, University of Toronto, Toronto, Ontario.

Hobbs, J.E. 1980. Studies in physical geography. Applied climatology: a study of atmospheric resources. Butterworths, London. 218 pp.

Holmgren, B. 1971. Climate and energy exchange on a subpolar ice cap in summer, Part F: On the energy exchange of the snow surface at Ice Cap Station. Arctic Institute of North America, Devon Island Expedition 1961-1963. Meterologiska Institutionen, Uppsala, Sweden. 53 pp.

Koerner, R.M. 1979. Accumulation, ablation and oxygen isotope variations on the Queen Elizabeth Islands ice caps, Canada. Journal of Glaciology 22:25-41.

Maxwell, J.B. 1980. The climate of the Canadian Arctic Islands and adjacent waters. Volume 1. Atmospheric Environment Service, Climatological Studies No. 30:1-532.

______. 1982. The climate of the Canadian Arctic Islands and adjacent waters. Volume 2. Atmospheric Environment Service, Climatological Studies No. 30:1-589.

McKay, D.C. and R.J. Morris. 1985. Solar radiation data analyses for Canada 1967-1976. Volume 6: The Yukon and Northwest Territories. Canadian Climate Program.

Müller, F., H. Blatter, R. Braithwaite, H. Ito, G. Kappenberger, A. Ohmura, K. Schroff, and A. Zust. 1976. Report on North Water project activities, 1 October 1974 to 30 September 1975. Progress report. McGill University and Swiss Federal Institute of Technology. Unpublished manuscript. 149 pp.

Ohmura, A. 1981. Climate and energy balance on arctic tundra: Axel Heiberg Island, Canadian Arctic Archipelago, spring and summer 1969, 1970 and 1972. Eidgenussiche Technische Hochschule, Zurich. Zuricher Geographische Schriften 3:1-448.

Vowinckel, E. and S. Orvig. 1962. The climate of the North Polar Basin. In: World Survey of Climatology, Volume 14. Edited by: S. Orvig. Elsevier, Amsterdam. pp. 129-252.

Wallén, C.C. 1977. Climates of central and southern Europe. World Survey of Climatology, Volume 6. Elsevier, Amsterdam. 248 pp.

Woo, M-K., R. Heron, P. Marsh, and P. Steer. 1983. Comparisons of weather station snowfall with winter snow accumulation in High Arctic basins. Atmosphere-Ocean 21(3):312-325.

Illustrated by Brenda Carter

L'EXPOSITION DES PLAQUES DE NEIGE RÉSIDUELLES DANS L'ARCTIQUE CANADIEN

Lagarec, Daniel[1], Bernard Lauriol[1], et Daniel Devocht[1]

Résumé: Dans l'arctique canadien, la neige subsiste durant tout ou une partie de l'été sous trois formes: les glaciers, les champs de neige et les plaques de neige. Les deux premiers types sont principalement concentrés sur la façade orientale des îles de Baffin, Devon et Ellesmere. Par opposition, les plaques, elles, se rencontrent sur à peu près toutes les îles, bien qu'elles soient plus nombreuses dans la région du détroit d'Hudson que sur les îles de l'ouest de l'arctique.

L'objectif de cet article est de montrer que l'exposition des plaques de neige à travers l'arctique canadien pour l'été de 1958 pour lequel plusieurs couvertures aériennes sont disponibles est expliquée par la direction des vents de l'hiver précédent.

L'épaisseur maximale de neige au sol est la plus forte dans la péninsule de l'Ungava avec 195 cm et décroît jusqu'à 18-25 cm dans le nord-ouest. Elle est atteinte habituellement entre le 1er mars et le 1er mai. Dans la plupart des stations, la neige a disparu le 1er juillet.

On observe un patron assez clair d'exposition des plaques de neige: (1) dans l'ouest, la direction dominante est E à SE; (2) dans l'est, elle est essentiellement SW à NW; (3) dans la partie centrale, comme sur la péninsule de Boothia, il est moins bien défini avec toutefois une dominante SSE.

Dans l'ensemble, ce patron est conforme à la direction des vents dominants de l'hiver, les plaques de neige subsistant sur le côté sous le vent. Dans quelques cas exceptionnels, l'exposition des plaques de neige est déterminée par la direction du vent pendant les mois à fortes chutes de neige.

Abstract: In the Canadian Arctic, snow remains on the ground in summer as glaciers, snowfields or snowbanks. The first two types are mainly located on the eastern margins of Baffin, Devon and Ellesmere islands. In contrast, snowbanks may be found on almost every island, although they are more numerous around Hudson Strait than on the western islands of the archipelago.

The aim of this paper is to show that the orientation of snowbanks across the Canadian Arctic for the summer of 1958, for which several aerial-photograph coverages are available, is explained by the direction of the previous winter winds.

Maximum snow-depth of 195 cm was observed in the Ungava Peninsula and decreased to a minimum of 18-25 cm in the northwest. The maximum depth is usually achieved between March 1 and May 1. At most stations, snow has melted by July 1.

A clear pattern of orientation of snowbanks appears: (1) in the western region, the dominant direction is E to SE; (2) in the East, it is mainly SW to NW; (3) in central locations, for example on Boothia Peninsula, it is less defined, with however a SSE dominance.

Overall this pattern is consistent with winter prevailing winds, the snowbanks resting on the leeside of raised features. In exceptional cases, snowbank orientation is related to the wind direction of months with heavy snowfalls.

INTRODUCTION

Dans l'Arctique canadien, la neige subsiste durant tout ou une partie de l'été dans trois types de situations: les glaciers, les champs de neige et les plaques de neige. Les deux premiers sont principalement concentrés sur la façade orientale des îles de Baffin, Devon et Ellesmere. Les plaques, elles, se rencontrent sur à peu près toutes les îles, bien qu'elles soient plus nombreuses dans la région du détroit d'Hudson que sur les îles de l'Ouest de l'Arctique (Lauriol *et al.* 1984, 1986).

Les raisons de la distribution inégale des surfaces enneigées en été résident essentiellement dans des différences climatiques; il semble notamment qu'il y ait une relation entre l'épaisseur de la neige au sol à la fin de l'hiver et la superficie occupée par la neige à la fin du mois de juillet. Cette relation paraît assez forte pour qu'on puisse envisager la possibilité d'utiliser la surface résiduelle de la neige comme moyen de connaître l'épaisseur de la neige au sol à la fin de l'hiver (Lauriol *et al.* 1986).

---

[1] Département de Géographie, Université d'Ottawa, 165 rue Waller, Ottawa, Ontario K1N 6N5

Dans le présent article, nous voulons montrer et expliquer les caractéristiques de l'exposition des plaques de neige à travers les îles de l'Arctique canadien pour l'été 1958.

MÉTHODOLOGIE ET OBJECTIFS

Les objectifs de l'étude sont d'identifier des zones où l'exposition des plaques de neige est homogène et d'évaluer la relation entre celle-ci et l'orientation des vents à une station météorologique proche. L'exposition des plaques de neige a été déterminée à partir de photographies aériennes de la Photothèque Nationale et les données sur les vents ont été extraites des sommaires climatiques mensuels d'Environnement Canada. Il est à noter que nous avons conservé la toponymie en vigueur à cette époque.

Bien qu'en règle générale, d'une année à l'autre, les plaques de neige se retrouvent aux mêmes endroits, il a paru utile pour faciliter les comparaisons de n'utiliser que des photographies prises au cours de l'été 1958. Le choix de cette année s'explique par la couverture extensive existant pour cette année-là.

Le problème le plus difficile à surmonter fut de trouver des zones où les accidents topographiques à l'abri desquels la neige était susceptible de s'accumuler, n'offraient aucune orientation dominante ou contraignante. Celles qui se prêtaient le mieux à l'analyse étaient les plateaux sur lesquels se rencontraient quelques accidents topographiques, en relief ou en creux, offrant des possibilités d'exposition variées.

RÉSULTATS

L'exposition des plaques de neige a été mesurée selon un système de huit points cardinaux. Toutefois pour simplifier la représentation et permettre des comparaisons, nous avons calculé pour chaque site la direction moyenne ainsi que le vecteur résultant qui se

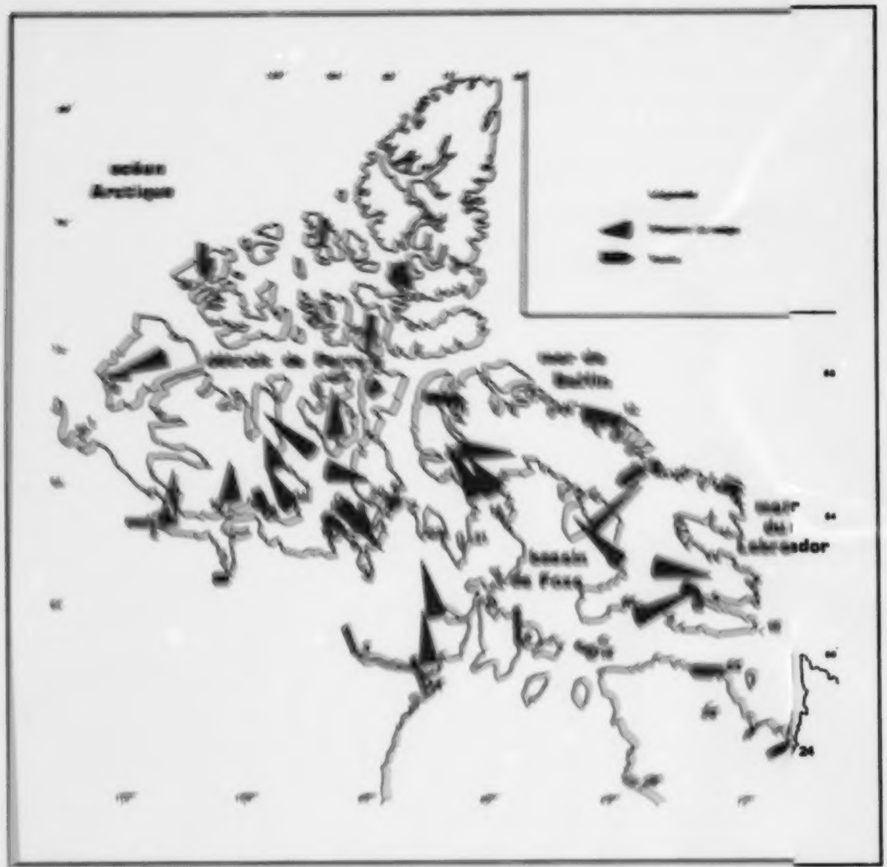

océan Arctique
détroit de Barrow
mer de Baffin
bassin de Foxe
mer du Labrador
Légende
24

FIGURE 1: *Orientation dominante des plaques de neige et des vents au cours de l'hiver 1957-1958.*

revient à exprimer l'intensité du groupement autour de la direction moyenne. De sorte que sur la figure 1, la longueur du symbole utilisé reflète le vecteur résultant et la largeur l'erreur-type au seuil de 95 % (Davis 1986).

Les coordonnées de l'extrémité de chaque vecteur dont la direction est représentée par l'angle Θ sont:

$$X_i = \cos \Theta_i$$
$$Y_i = \sin \Theta_i$$

Le vecteur résultant est obtenu en sommant les sinus et cosinus de chaque vecteur. La direction moyenne est alors déterminée par:

$$[1] \quad \bar{\theta} = \tan^{-1} \left(\sum_{i=1}^{n} \sin \theta_i \Big/ \sum_{i=1}^{n} \cos \theta_i \right)$$

et longueur du vecteur résultant R est donnée par le théorème de Pythagore:

$$[2] \quad R = \sqrt{\left(\sum_{i=1}^{n} \cos \theta_i \right)^2 + \left(\sum_{i=1}^{n} \sin \theta_i \right)^2}$$

et dépend de la taille de la population considérée. Pour permettre les comparaisons, on peut standardiser en calculant la longueur moyenne $\bar{R}$ en divisant la longueur du vecteur résultant par le nombre de cas. Ce nouveau paramètre a une valeur comprise entre 0 et 1 et représente une mesure de dispersion analogue à la variance, mais exprimée en sens inverse: des valeurs élevées indiquent que les observations sont bien groupées autour de la moyenne, alors que des valeurs faibles indiquent une forte dispersion. Il serait plus juste de parler d'indice de concentration.

Sur la figure 1 montrant les informations ainsi schématisées pour chaque site, on peut distinguer trois grandes régions:

(1) À l'Ouest, sur les îles Banks et Victoria, l'orientation dominante est d'Est à Sud-est et l'indice de concentration est supérieur à 0.5, atteignant un maximum de 0.815 dans le Nord de Victoria;

(2) À l'Est, en bordure de la mer de Baffin (îles de Baffin, Somerset et Devon), la dominance se situe dans le secteur Sud-ouest à Nord-ouest et la dispersion augmente vers le Nord-ouest alors que l'indice de concentration passe d'un maximum absolu de 0.926 dans le centre de l'Île de Baffin à un minimum absolu de 0.169 sur l'Isle de Somerset;

(3) Entre les deux, on retrouve une zone plus hétérogène avec néanmoins une dominance d'orientation Sud sud-est et une diminution de la dispersion vers le sud, dans le district de Keewatin, où l'indice atteint 0.7.

Afin de tenter d'expliquer ce patron, il est important de bien connaître les conditions climatiques d'ensemble de l'hiver responsables de la disponibilité en neige ainsi que des vents influençant sa mise en place. Il est à noter que nous avons conservé la toponymie en usage à l'époque et que les numéros de la figure 1 correspondent aux stations apparaissant dans le tableau 1.

TABLEAU 1: CHUTES DE NEIGE AU COURS DE L'HIVER 1957-1958 DANS L'ARCTIQUE CANADIEN (EN CM).

		AOÛT	SEPT	OCT	NOV	DÉC	JAN	FÉV	MARS	AVR	MAI	JUIN	TOTAL[1]	NORMALE[1]
1	Cape Parry	0	17.8	5.1	0.5	0.8	T	T	-	3.6	0.2	T	(35.0)	125.9
2	Coppermine	0	8.1	8.1	15.7	1.0	9.1	1.3	7.6	12.2	1.5	1.5	66.8	100.7
3	Baker Lake	0	7.9	10.4	6.6	2.0	8.6	0.2	6.6	5.8	3.8	1.5	53.6	100.0
4	Chesterfield	0	T	5.3	12.4	3.8	10.2	7.6	5.6	3.8	6.1	3.8	58.7	112.5
5	Coral Harbour	0	12.4	13.7	17.3	7.1	21.3	9.4	8.9	12.4	23.4	7.1	133.0	131.9
6	Cambridge Bay	T	8.4	12.7	18.0	4.8	13.0	4.1	10.9	5.1	5.6	3.8	86.4	76.8
7	Isachsen	11.4	2.5	6.6	T	T	1.3	3.3	0	0.5	7.6	0.3	33.5	81.3
8	Mould Bay	8.1	6.1	5.1	2.0	2.3	11.7	2.0	2.3	1.0	4.1	T	44.7	71.9
9	Sachs Harbour	T	5.1	7.9	2.8	0.8	2.3	1.3	1.0	2.0	1.3	0.3	39.9	76.0
10	Unnamed Point	0	7.1	29.0	T	1.3	2.8	2.5	0	3.6	3.0	3.6	52.8	45.8
11	Arctic Bay	T	10.7	13.2	1.3	0.8	6.6	4.8	1.8	0.8	0.3	1.5	41.7	71.5
12	Clyde	T	4.3	41.7	13.5	1.3	4.6	5.3	2.8	1.8	7.4	3.0	85.6	168.9
13	Frobisher Bay	4.3	1.3	53.8	62.7	63.5	76.5	45.5	66.3	73.9	30.0	12.4	490.2	255.5
14	Hall Lake	3.3	1.5	16.5	8.4	3.0	5.1	14.5	4.1	8.4	28.4	7.1	100.3	121.3
15	King William	0	7.6	-	8.1	2.5	23.4	3.6	31.4	1.0	7.9	-	(85.0)	51.2
16	Nottingham I.	T	21.1	27.7	33.0	32.3	33.3	11.2	8.6	32.0	16.5	29.7	245.4	149.8
17	Pond Inlet	0	0.6	2.0	T	T	0.8	1.6	0.6	T	5.1	-	(10.4)	(110.0)
18	Resolute	0.3	16.3	19.8	3.3	3.3	2.5	4.3	3.8	3.0	5.8	4.3	66.8	83.8
19	Resolution I.	T	3.8	21.1	20.1	30.7	12.2	12.2	7.4	6.4	24.1	-	(150.0)	155.4
20	Spence Bay	0	11.7	10.4	2.0	T	3.3	13.5	1.0	4.3	10.7	12.4	69.3	103.3
21	West Melville	-	-	-	12.2	0.8	1.8	20.6	1.5	16.8	28.4	2.3	(100.0)	97.0
22	West Simpson	0	26.9	19.3	42.2	0.5	10.7	5.6	7.6	36.3	10.7	6.4	165.6	127.1
23	Cape Hope	3.8	8.9	36.6	64.3	81.0	42.2	25.4	22.1	19.8	16.5	5.1	325.6	147.3
24	Fort Chimo	T	0.3	9.4	23.4	61.5	43.9	30.2	16.8	17.5	51.8	12.4	267.2	236.7
25	Payne River	-	0.5	14.7	82.6	76.2	-	-	-	-	32.5	8.9	-	-
26	Port Harrison	T	T	10.9	25.9	16.5	2.0	7.1	2.3	9.4	22.4	1.5	98.0	122.9

[1] Les valeurs entre parenthèses sont des estimations.

LES CONDITIONS CLIMATIQUES DE L'HIVER 1957-1958

Les caractères généraux de la circulation atmosphérique

Dans l'ensemble, la circulation en altitude (700 mb) se caractérise par une crête sur le Yukon et une vallée sur l'Est du pays. Ce patron est assez constant au cours de l'hiver, sauf en mars dont le cas sera discuté plus loin. Toutefois, son intensité varie et contribue à expliquer le régime des précipitations ainsi que l'asymétrie Est-Ouest de ces dernières: la crête sur le Yukon permet la pénétration limitée d'air humide sur la façade occidentale de l'archipel où le maximum des chutes de neige se produit en septembre-octobre, alors que la vallée orientale favorise la remontée d'air atlantique le long de la façade orientale; le déplacement vers le Nord du creux au cours de l'hiver se traduit par un décalage de la date du maximum des précipitations nivales qui arrive en novembre-décembre au sud du détroit d'Hudson et en janvier au Nord. En mars, une haute pression occupe la mer d'Hudson ce qui provoque une dominance du flux d'Ouest et de faibles chutes de neige, sauf sur la façade atlantique.

En surface, le champ de pression moyen résultant de cette circulation montre deux centres de haute pression, l'un centré sur le Keewatin et l'autre au Nord-ouest, et un centre de basse pression localisé sur la mer de Baffin. Barry (1960) a montré que le Nord de l'Ungava a connu au cours de l'hiver 1957-1958 une forte dominance de flux cycloniques du Nord-ouest, modifiés ou non (40 %), et d'Ouest (25 %).

Distribution des chutes de neige et de la neige au sol

La carte du total des chutes de neige (figure 2) montre une forte asymétrie de la distribution opposant le Sud-est et le Nord-ouest. Les maxima sont observés à Frobisher Bay (Iqaluit) (490 cm) et Cap Hopes Advance (326 cm). Deux zones de minima apparaissent dans le Nord de l'île de Baffin (10 cm à Pond Inlet) et sur la façade de l'Océan Arctique (33 cm à Isachsen). Si l'on compare avec les normales, on remarque que 15 stations sur les 26 utilisées ont des totaux inférieurs à celles-ci. Les 11 autres sont localisées le long d'un axe Cambridge Bay-Détroit d'Hudson.

Dans l'ensemble, octobre-novembre et mai sont les deux périodes recevant les plus grandes quantités, mais les régimes varient spatialement. Les stations du Nord-ouest ont

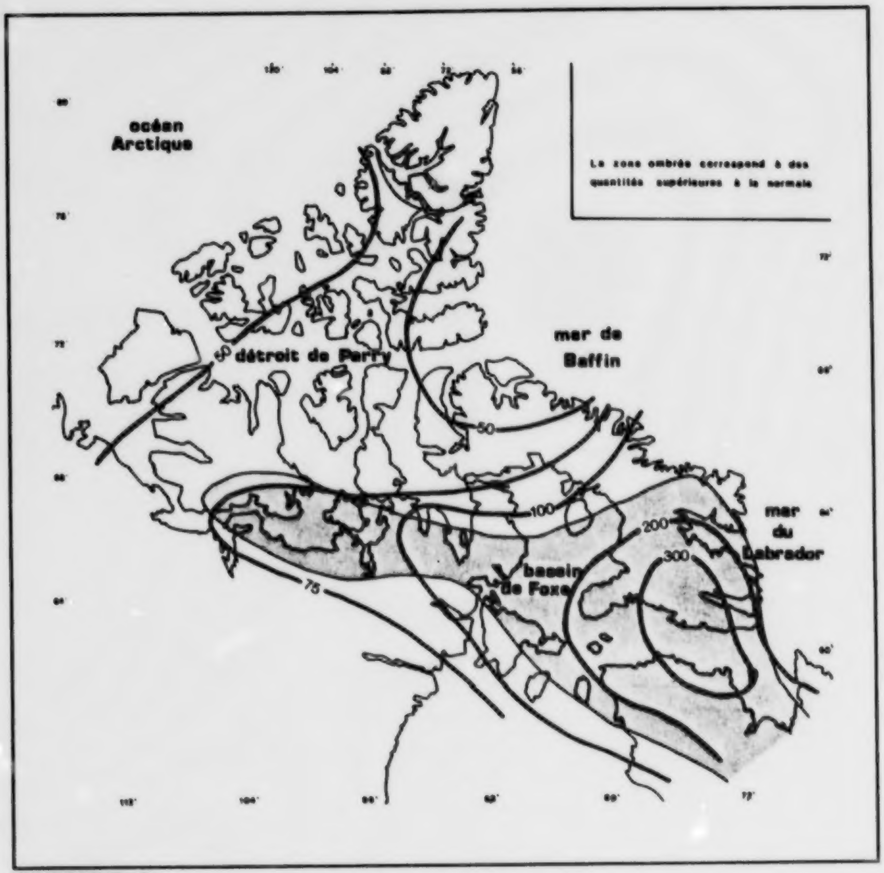

océan Arctique
La zone ombrée correspond à des quantités supérieures à la normale
détroit de Parry
mer de Baffin
50
100
200
300
75
mer du Labrador
bassin de Foxe

FIGURE 2: Chutes de neige de l'hiver 1957-1958 (en cm).

leur maximum au début de l'hiver, et même en août dans le cas d'Isachsen; celles d'Ungava au coeur de l'hiver et celles de la partie centrale (Keewatin oriental) en mai. Frobisher Bay (Iqaluit) constitue une exception, les chutes étant abondantes pratiquement d'octobre à mai.

L'épaisseur maximale de neige au sol est la plus forte autour du détroit d'Hudson avec un maximum de 195 cm dans l'Ungava, et décroît selon un gradient Sud-est-Nord-est, pour n'être plus que de 18 à 25 cm le long du littoral arctique. Elle est atteinte le plus souvent le 1er mai, à l'exception de l'Ungava, du nord de l'île de Baffin et des îles du Nord-ouest où cela se produit le 1er avril ou même le 1er mars. Ce patron reflète assez bien celui des chutes de neige. Quelques différences sont à noter par rapport aux normales. Ainsi les valeurs sont plus fortes dans l'axe Cambridge Bay-Détroit d'Hudson. Mais surtout, il semble que les dates du maximum sont dans l'ensemble plus tardives d'environ un mois.

Pour la plupart des stations, la neige a disparu le 1^{er} juillet. La fusion est le plus souvent un phénomène catastrophique, comme à West Simpson où l'on passe de 104 cm le 1^{er} juin à 2.5 cm le 1^{er} juillet (Tableau 2). Dans l'est, l'essentiel de la fonte a lieu en mai. Selon les normales, la neige a généralement disparu le 1^{er} juillet à l'exception de quelques îlots sur Baffin qui peuvent durer jusqu'au 15 juillet (Maxwell 1980).

TABLEAU 2: HAUTEUR DE NEIGE AU SOL, 1957-1958 (EN CM).

		SEPT	OCT	NOV	DÉC	JAN	FÉV	MARS	AVR	MAI	JUIN
1	Cape Parry	12.7	15.2	15.2	15.2	18.0	18.0	18.0	18.0	18.0	0
2	Coppermine	5.1	7.6	18.0	20.3	27.9	27.9	35.6	43.2	10.2	0
3	Baker Lake	T	5.1	7.6	15.2	20.3	20.3	22.9	25.4	20.3	2.5
4	Chesterfield	0	2.5	18.0	22.9	35.6	45.7	48.3	45.7	33.0	2.5
5	Coral Harbour	T	7.6	18.0	20.3	35.6	38.1	40.6	45.7	33.0	T
6	Cambridge Bay	2.5	20.3	35.6	38.1	45.7	48.3	55.9	58.4	45.7	0
7	Isachsen	2.5	12.7	12.7	12.7	12.7	15.2	15.2	15.2	18.0	T
8	Mould Bay	2.5	7.6	10.2	10.2	22.9	22.9	25.4	25.4	25.4	T
9	Sachs Harbour	7.6	12.7	18.0	18.0	20.3	20.3	22.9	22.9	25.4	T
10	Unnamed Point	2.5	15.2	18.0	20.3	25.4	25.4	27.9	18.0	7.6	0
11	Arctic Bay	0	7.6	12.7	15.2	20.3	27.9	30.5	30.5	27.9	2.5
12	Clyde	T	40.6	53.3	55.9	61.0	66.0	68.5	68.5	61.0	5.1
13	Frobisher Bay	0	10.2	20.3	38.1	30.5	45.7	61.0	86.4	12.7	0
14	Hall Lake	T	10.2	18.0	20.3	25.4	35.6	35.6	43.2	30.5	T
15	King William	7.6	-	45.7	48.3	71.1	78.7	91.4	55.9	10.2	-
16	Nottingham I.	T	7.6	38.1	71.1	104.1	114.3	104.1	127.0	30.5	T
18	Resolute	12.7	18.0	22.9	20.3	18.0	20.3	20.3	20.3	20.3	0
19	Resolution I.	T	12.7	38.1	68.5	78.7	86.4	88.9	38.1	27.9	-
20	Spence Bay	7.6	12.7	12.7	12.7	15.2	20.3	20.3	22.9	20.3	T
21	West Melville	-	-	40.6	40.6	30.5	43.2	38.1	48.3	35.6	0
22	West Simpson	20.3	38.1	50.8	50.8	61.0	63.5	71.1	106.7	104.1	2.5
23	Cape Hope	0	18.0	63.5	94.0	78.7	94.0	96.5	91.4	43.2	10.2
24	Fort Chimo	0	5.1	10.2	48.3	58.4	71.1	33.0	20.3	10.2	0
25	Payne River	0	7.6	71.1	137.2	177.8	188.0	177.8	195.6	152.4	-
26	Port Harrison	0	5.1	27.9	45.7	48.3	55.9	48.3	30.5	5.1	T

Pour des chutes de neige inférieures à 100 cm, la relation hauteur de neige au sol/précipitations est relativement bonne et linéaire:

[3] Hmax = 1.08P - 15 cm (r=0.846; significatif à 0.001).

Quand les précipitations sont supérieures à ce seuil, aucune relation n'apparaît clairement.

Les vents

L'orientation des vents a été appréhendée de la même façon que celle des bancs de neige, c'est-à-dire que pour chaque station, on a déterminé l'orientation moyenne, l'erreur-type au niveau 0.05 et le vecteur moyen. Ces données apparaîssent sur la figure 1. Lors du calcul de ces paramètres, nous n'avons pas tenu compte des calmes. Il convient de noter que ceux-ci présentent une organisation spatiale très nette selon un gradient Nord-est-Sud-ouest, avec un maximum supérieur à 40 % dans le nord de l'Île de Baffin et une décroissance vers le Sud-ouest où les valeurs sont inférieures à 10 %.

L'orientation moyenne des vents présentée sur la figure 1 correspond assez bien à celle déduite du champ de pression moyen pour la période. D'une dominante Nord-Nord-ouest au sortir du centre de haute pression localisé dans la partie occidentale de l'archipel ou Ouest quand ils viennent de celui du Keewatin, la direction des vents s'infléchit progressivement à Nord-ouest dans la partie centrale jusqu'à devenir franchement d'Ouest en Ungava.

L'indice de concentration montre un patron en ensellement avec des valeurs supérieures à 0.5 dans la partie centrale diminuant de part et d'autre. La relative stabilité des orientations dans la partie centrale s'explique par le caractère transitionel de cette région, alors que dans les deux autres, les centres de hautes et basses pressions se déplacent légèrement au cours de l'hiver.

CONCLUSION

L'examen de l'orientation des plaques de neige et des vents dominants montre qu'il existe dans l'ensemble une assez bonne concordance entre les deux et que la neige se dépose du côté sous le vent. Toutefois quelques disparités apparaissent sur la figure 1. Si l'on regarde ces cas déviants de plus près, on constate que généralement les plaques de neige s'organisent non pas par rapport au vent moyen de l'hiver, mais par rapport à un vent dominant ou sous-dominant d'un mois où les chutes de neige ont été relativement importantes. Le secteur de Baffin constitue un des cas déviants les plus typiques avec des dominantes d'orientation vers un secteur Sud-ouest-Nord-ouest. Or, au début de l'hiver quand se produisent des chutes de neige assez abondantes, les vents dominants ou sous-dominants viennent du secteur Nord-est à Sud-est et c'est aussi l'époque où ils sont les plus forts (6.3 m/s).

Dans le cas de l'île de Banks, l'orientation dominante des bancs de neige est vers l'Est et les vents dominants viennent de l'Est. Mais en octobre quand tombe une bonne partie des précipitations neigeuses, les vents dominants viennent de l'Ouest et c'est aussi le mois où ils sont les plus forts (7.3 m/s).

L'examen des cas déviants permet d'avancer que la formation des plaques de neige est sans doute précoce et se produit au début de la saison nivale par l'apparition de noyaux autour desquels elles vont se développer. Les vents forts relevés pour cette époque contribuent en effet à augmenter la densité de la neige accumulée (Föhn 1980).

REMERCIEMENTS

Les auteurs remercient l'École des Études Supérieures de l'Université d'Ottawa qui a partiellement financé cette recherche; Daniel Devocht a bénificié d'une bourse du 1^{er} cycle du Conseil de Recherche en Sciences Naturelles et Génie.

RÉFÉRENCES

Barry, R.G. 1960. The application of synoptic studies in palaeoclimatology: a case study for Labrador-Ungava. Geografiska Annaler 42(1):36-44.

Davis, J.C. 1986. Statistics and data analysis in geology. 2nd Edition. Wiley, New York. 646 pp.

Föhn, P.M.B. 1980. Snow transport over mountain crests. Journal of Glaciology 26(94):469-480.

Lauriol, B., A. Champoux, et J.T. Gray. 1984. Répartition estivale des surfaces enneigées en Ungava, Nouveau-Québec. Géographie physique et Quaternaire 38(1):37-47.

Lauriol, B., Y. Carrier, H. Beaudet, and G. Binda. 1986. The residual snow cover in the Canadian Arctic in July: a means to evaluate the regional maximum snow depth in winter. Arctic 39(4):309-315.

Maxwell, J.B. 1980. Le climate des îles arctiques et des eaux adjacentes du Canada. Volume 1, Études climatologiques n° 30, Environnement Canada, Service de l'Environnement Atmosphérique. 531 pp.

ARCTIC METEOROLOGY AND CLIMATOLOGY, PRESENT STATE AND FUTURE DIRECTIONS

Claude L. Labine[1]

Abstract: A review of the problems of meteorology and climatology of the Canadian Arctic Islands is presented. Problems with the existing database are dealt with first: low density of stations; coastal nature of data; few long-term studies. Further, radiation and surface energy-balance data indicate that there are some basic problems remaining. Permafrost research in the Arctic Islands needs to be more closely linked to surface energy exchanges and climatic change. The largest polynya in the region, the North Water, still needs to be properly understood.

Some positive steps have occurred in the past few years; the air-quality monitoring program at Alert, and the Atmospheric Environment Service climate-permafrost program are two examples. A lack of a clear government northern policy is considered to be the main drawback affecting all research in the Arctic Islands.

Résumé: Les problèmes de météorologie et climatologie des îles de l'arctique sont présentés. Les problèmes de la présente base de données sont discutés en premier: basse densité de stations, influence côtière de l'information, très peu d'études à long terme. L'information du bilan de radiation et d'énergie de la surface démontre encore des problèmes de base. L'étude du pergélisol dans les îles de l'arctique a besoin d'être plus lié aux flux d'énergie de la surface et au changement de climat. La plus grande polynya des îles, l'Eau du Nord, a besoin d'être mieux comprise.

Il y a eu plusieurs directions positives durant les dernières années; l'établissement d'une de station de surveillance de qualité d'air à Alert et l'initiation d'un programme de recherche du pergélisol et le changement de climat sont deux examples. Un manque d'une politique nordique clair et ferme de la part du gouvernement fédéral, est un des grands désavantages qui affectent toute recherche dans les îles de l'arctique.

INTRODUCTION

In preparing papers for this volume, we were asked to establish the highlights of the subject, detect significant gaps in our present understanding, suggest ways of filling such gaps and list basic references. These goals were pursued, as well as two others. The first is from Hattersley-Smith (1982) who reviewed the last Arctic Islands conference held in 1980 in Yellowknife (Zaslow 1981). Unfortunately, that conference did not seem to contribute much forward direction but looked back on past accomplishments. As Hattersley-Smith states: "The scientific research papers provide useful summaries of past field work and of knowledge acquired, but some fall short in identifying the main problems to be resolved and in charting the course of future work". Because there has been no similar conference since then, it is imperative that we attempt to focus on the present status of our various disciplines and suggest possible directions.

---

[1] Campbell Scientific Canada Corporation, 9525 41st Avenue, Edmonton, Alberta T6E 5X7

The final guidelines used in writing this paper is from Hare (1968), who stated that: "The climatological view of the Arctic absolutely demands the interdisciplinary approach". This is probably true of most arctic scientific disciplines and also implies that some of the points raised in this paper can be applied to other research fields. The interdisciplinary nature of the problem also implies non-scientific influences upon arctic research such as economics, northern government policy, land-claims and arctic sovereignty. Researchers cannot avoid being influenced by these elements. In trying to review and synthesize a discipline, at least the implications of these non-scientific influences should be considered, in order to see how such issues can be best incorporated in the continuing advancement of knowledge about the Arctic Islands - Canada's most unique geographical feature.

PRESENT PROBLEMS

Research Activity

The task of analyzing the present situation and potential direction of arctic meteorology and climatology is not as difficult as it might seem at first. Three important publications in recent years have made the task much easier by presenting extensive overviews of past research (Maxwell 1981; Ohmura 1982A) and, more importantly, by indicating some of the problems in arctic meteorology and climatology (Maxwell 1980). These publications are the best basic references now available. Maxwell's (1980) work is the best source of synthesized climatic data available, and will probably remain a major reference for years to come. Ohmura's (1982A) study offers an excellent historical perspective, not only on energy-budgets but on both meteorology and climatology. My task is therefore reduced to reviewing the past six years of activity, before considering continuing problems and potential directions. This requirement is readily met since the last five years has been a period of the least amount of research activity for meteorology and climatology in the Arctic Islands since the 1951-1955 period following the establishment of the Joint American Canadian Weather Stations in the late 1940s (Figure 1).

The main characteristics of Figure 1 are: (1) the increase of activity since the establishment of the main synoptic weather stations; (2) the peak of activity in the late 1970s; followed by (3) reduction to present levels. Similar data on oceanography in the

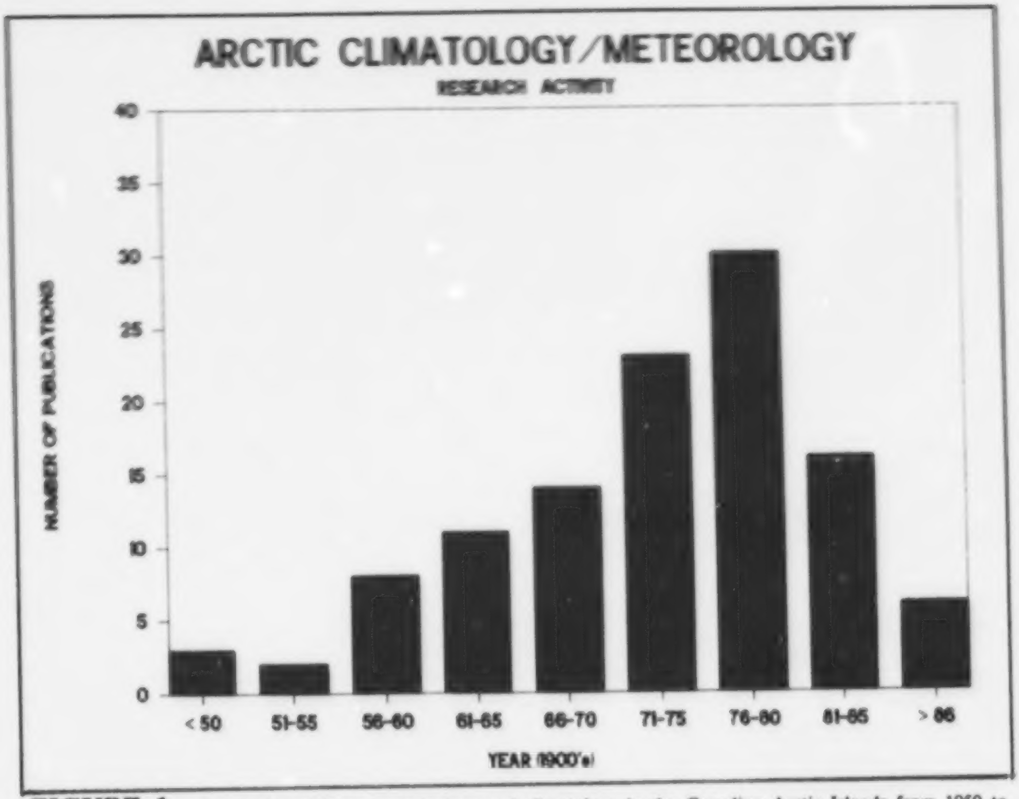


FIGURE 1: Research activity in meteorology and climatology in the Canadian Arctic Islands from 1950 to 1987. Research activity is here defined as the number of research papers published.
Sources: Maxwell 1980, 1981; Ohmura 1982A; Arctic Scientific and Technological Information Services of the Arctic Institute of North America (ASTIS).
Key words used in the search: meteorology, climatology, hydrology, glaciology, oceanography, water-quality.

Canadian Arctic Islands were discussed by Smiley (1987). Both sets of information show how the search for oil in the Canadian Arctic during the early and mid-1970s coincided with an increase in research activity. In many situations the increase in research activity was as a result of the increase in oil exploration.

Since then, there have been few research projects where the emphasis was on meteorology or climatology. Hydrometeorlogical work by Woo and Marsh (Marsh and Woo 1981; Woo *et al.* 1983) at Resolute was a major contribution to our understanding of the precipitation regime of the Arctic Islands. Research by Bradley and others (Bradley and Serreze 1987; Serreze and Bradley 1987) on a small ice cap was an attempt to understand the processes related to ice sheet-growth and climatic change. Another important meteorological research activity is the work being conducted on "Arctic Haze" by the Atmospheric Environment Service (Barrie and Hoff 1985; Barrie *et al.* 1981). Alt's (1987) work represents one of the longest sustained efforts of meteorological research in the islands, and is an important contribution to the synoptic climatology of the area. And the glaciological-paleoclimatological research pursued by Koerner (Koerner 1985; Koerner and Fisher 1985) is essential to our understanding of climatic change.

Further proof of the lack of activity in the islands comes from simply reviewing meteorological or climatological projects supported by the Polar Continental Shelf Project. In the last five years there have only been a few active research projects there: Alt's and Koerner's studies, as well as my work (Labine 1988) involving High Arctic oases. Other research projects, where meteorological or climatological aspects were secondary,include a study on a polar semidesert by Addison and Bliss (1980). Unfortunately, these projects were short-term.

This brings us to an apparent problem with arctic meteorology and climatology. In Canada, there is only one university-based research group active in these disciplines. Fortunately, a group once based at McGill University (Hare 1968; Vowinckel and Orvig 1963) has been reconstituted recently as the McGill University Climate Research Group (Harington 1989). There have been some recent visits to the McGill station at Axel Heiberg Island (personal communication, P. Adams), but there are no present plans to pursue long-term climatological or meteorological research from that base. A recent publication, however, dealt with glaciology and some elements of climatic change in that vicinity (Blatter 1987). Last year, Jacobs (Jacobs *et al.*, this volume), from the University of Windsor, initiated a multidisciplinary project on Baffin Island within the context of climatic change. One could argue that research need not be based at a university. Indeed, the majority of present activity is almost exclusively within the federal government - specifically the Arctic Meteorology Section of the Canadian Climate Centre. The central long-term research project undertaken by this group is also involved with climatic change and permafrost. A problem arising from the scarcity of strong university-based groups is that we are not training enough students to deal with the problems of meteorology and climatology in the Arctic Islands.

The Existing Database

As will be shown, there is already an increase in the number of projects directly or indirectly involved with meteorological and climatological research in the Arctic Islands. Although this is promising, it neither removes nor diminishes the impact of existing problems. Simultaneously, this increase in activity will create other problems which need to be addressed. Maxwell (1980, 1981) best summarizes the problems associated with the existing climatic database. The low density of stations is the most obvious characteristic of the synoptic network. With the closing of Isachsen in 1978, only four of the original weather stations are left in the Queen Elizabeth Islands: Alert, Eureka, Resolute and Mould Bay. Although the closing of Isachsen could be justified economically, why was no automatic station established there to at least maintain the database? The existing one was obtained at great expense; the cost of continuing to record the basic parameters would have been insignificant compared to the yearly operating costs of the High Arctic Weather Stations.

Maxwell (1981) also points out that all of these stations are situated on the coasts and certainly bias the database. The strongest gradients occur near the coast (Green 1977) and this database would certainly not show the greater extremes of continentality occurring inland. For example, the difference between a coastal station and one situated 1 km inland on the Alexandra Fiord lowland is clear (Figure 2).

Finally, Ohmura (1982B) states that "In terms of field experimentation, there is no single project which has been continued long enough to be climatologically reliable, and no theoretical or empirical computation scheme of satisfactory accuracy has been developed." Maxwell (1981) also states that "... long term inland and offshore observational programs are relatively few". Obviously, there is a need for long-term research away from the established, staffed stations. It is almost impossible to obtain guaranteed funding for many years, given the nature of our government budgetary system. However, a recent project shows that relatively long-term funding can take place even during a change of government. This was the Northern Oil and Gas Project (NOGAP), which had a seven-year life span. Given the growing interest in climatic change, there needs to be some type of long-term project to determine how the climate is varying. The Arctic Islands are in a unique situation to be the first area to show significant climate change (Bentley 1984).

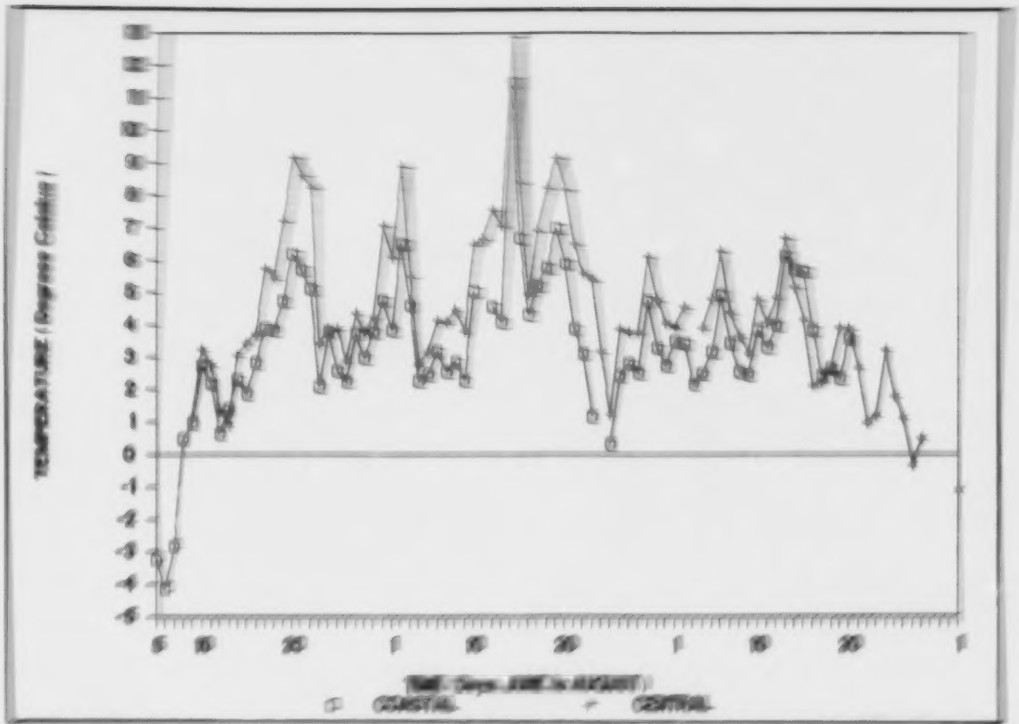


FIGURE 2: *1.5 m air temperature at a coastal station and a central station at Alexandra Fiord, Ellesmere Island. The central station is located approximately 1 km inland from the coast. Note the markedly higher inland temperatures.*

Radiation and Surface Energy-Balance

After completing our studies on the oasis area at Truelove Lowland, Devon Island, we (Courtin and Labine 1977) concluded that one of the main reasons that these areas existed was the increased amount of absorbed (net) radiation available to the ecosystem. At the time of the project, in the early 1970s, the Atmospheric Environment Service was just starting radiation measurements in the High Arctic, and we compared our data to the modeled radiation data for Resolute, the closest station. There are now 15 years of data and we find that although the measured values for Resolute are still half of the radiation measured at Truelove Lowland, the net radiation-values for Eureka, Isachsen and Mould Bay are as high as our values for Truelove Lowland. Maxwell (1981) in discussing these data, offers no explanation for this unusual pattern.

Another radiation-related problem stems from Ohmura's statement: 'The surfaces of the tundra, Arctic Ocean, and the ablation area of polar glaciers were found to receive similar net radiation during the snow-free period despite considerable albedo differences among them". Recent data (Bradley and Serreze 1987) show that there *are* differences in the net radiation values of these surfaces. This indicates that the radiation and energy-balance of surfaces in the Arctic need to be clarified. Radiation and energy-balance characteristics of a surface are at the heart of many other climatic and meteorological factors, and significantly affect permafrost and other parts of the ecosystem.

Polynyas

Heat exchanges occurring over open water were briefly studied at a polynya near Dundas Island (Topham *et al.* 1983). Despite the project's brevity, the results revealed facts about the influence on local ocean currents. Although useful, the data from this small polynya has limited application to the largest polynya in the Canadian Arctic Islands, the North Water, situated in northern Baffin Bay. This large ice-free area was the subject of an intensive study known as the North Water Project in the mid-1970s. Unfortunately, with the death of its director, Dr. F. Müller, a complete, detailed report was never produced. The data are at the Swiss Federal Institute in Zurich. Although perhaps impossible at present, consideration should be given to funding completion of the analysis.

Permafrost

Important, albeit largely descriptive, permafrost research in the Arctic Islands was undertaken by Brown (1972, 1977). Unfortunately, his death left a major gap in this endeavour, and his position at the National Research Council was never replaced. The main permafrost research in the Arctic Islands is now being carried out through Energy, Mines and Resources Canada. This research involves either monitoring temperatures in deep wells (Taylor *et al.* 1983) or permafrost in ocean sediments (Taylor and Allen 1985). Since permafrost is a good integrator of different climatic variables, it is also a good indicator of climatic change. The Arctic Meteorology Section of the Canadian Climate Centre has initiated a climate permafrost program (personal communication, B. Maxwell). Although most of the initial work is in the Low Arctic (Norman Wells, N.W.T.; Churchill, Manitoba; and Schefferville, Quebec), there is a potential for expanding the work to the Arctic Islands. The main information gap involves the influence of climate on permafrost, and requires a better understanding of the surface energy budget in relation to the permafrost layer. Some research of this kind was initiated by Smith (1975) on the Fosheim Peninsula, Ellesmere Island, but was of short duration.

Summary of Problems

Specifically, the outstanding problems in meteorology and climatology in the Canadian Arctic Islands are as follows:

(1) Low density of permanent weather stations.
(2) The existing network of stations is mainly coastal and therefore non-representative.
(3) A lack of long-term, continuous research.
(4) Confusion about some aspects of the radiation and energy budget.
(5) A need to properly assess the influence of polynyas on meteorology.
(6) A need to improve knowledge of climatic links to permafrost.
(7) Too few strong university-based research groups.
(8) Few active research projects.

Associated with these problems is the lack of a clear northern policy or commitment on the part of the Canadian Government. We claim sovereignty over the Arctic Islands, yet this claim is not supported by a strong dedication to research there. This lack of policy is best exemplified by events surrounding the passage of the United States Coast Guard ship *Polar Sea* through the North-West Passage. A few weeks after this controversial voyage, our company was asked, as suppliers of data-acquisition systems, to quote on a dozen automatic weather stations for deployment along the Passage. this was an immediate *reaction* to the event and not part of government policy to improve weather-monitoring or climatological knowledge along this important sea-route. As long as we have no clearly-defined policies or direction, we will always be reacting to events as they arise, leading to a haphazard development of research priorities.

One exception, and the saving grace as far as arctic research is concerned, is the Polar Continental Shelf Project (PCSP). As stated by Orvig (1981): "The most important project in the Canadian Arctic, in the present context, must be said to be the imaginative Polar Continental Shelf Project which has placed Canadian Arctic research and field operations among the world's best". This agency was created as part of John Diefenbakers's "northern vision". Without it, research in the Arctic Islands would be impossible. Obviously, PCSP suggests a strong commitment by the government to research in the islands. But this commitment must be questioned when the agency's budget has been continuously decreased since 1984. This decrease in funding was recently reversed as a result of a fortuitous meeting of arctic researchers with the deputy prime minister (press conference with D. Mazankowski, Edmonton, April 8, 1988). What makes the government's commitment to research even more questionable is the contrast between its long-term research funding and its recent plans to spend 8 to 14 billion dollars on nuclear submarines. One of the main arguments used in favour of this plan is arctic sovereignty. This is a complex issue involving many interests, however, the contrast mentioned is too strong to ignore. Obviously, the non-military presence of scientists in the Arctic Islands is a much less expensive alternative. The absence of a strong federal government policy supporting northern research is in part due to a continuing analysis bearing on possible creation of a national northern institute, and in part to the settlement of native land-claims. Once these issues have been properly dealt with, perhaps long-term support for arctic research, not only in meteorology and climatology but for all disciplines, will be established.

FUTURE DIRECTIONS

There have been some positive developments in the past few years that help to balance existing problems. The establishment of an excellent air-quality monitoring station at Alert will provide the necessary database to understand air quality and its influence on climatic change. The initiation of the climate-permafrost monitoring program, albeit confined to the Low Arctic, helps fill a gap left by the late Roger Brown. The creation of readily usable software packages by the Atmospheric Environment Service (Maxwell 1987) makes all forms of arctic meterological, climatological and sea-ice data much more accessible to a wide range of users. Finally, during this past field season, several groups from various disciplines have installed weather-monitoring equipment at various locations in the Arctic Islands. Most of the instruments are on Ellesmere Island (Tanquary Fiord, Lake Hazen, Fosheim Peninsula, Agassiz Ice Field, Cape Herschel and the Princess Marie Bay area), and two were on Bathurst Island. We can only hope that these systems will be operational long enough to produce climatologically-significant databases. An immediate problem is to coordinate these various databases and archive them so that the data will be accessible to a wide range of users (see Alt and Maxwell, this volume).

CONCLUSIONS

I consider the main problems of meteorology and climatology in the Canadian Arctic Islands to be: the paucity of researchers working in the field, and the paucity of strong university-based research groups. Although some positive steps have been taken, one of the main drawbacks to Arctic research as a whole, is the lack of an explicit, committed northern policy by the federal government.

REFERENCES

Addison, P.A. and L.C. Bliss. 1980. Summer climate, microclimate and energy budget of a polar semidesert on King Christian Island, N.W.T., Canada. Arctic and Alpine Research 12(2):161-170.

Alt, B.T. 1987. Developing synoptic analogs for extreme mass balance conditions on Queen Elizabeth Island ice caps. Journal of Climate and Applied Meteorology 26(12):1605-1623.

Barrie, L.A. and R.M. Hoff. 1985. Five years of air chemistry observations in the Canadian Arctic. Atmospheric Environment 19:1995-2010.

Barrie, L.A., R.M. Hoff, and S.M. Dasggupaty. 1981. The influence of mid-latitudinal pollution sources in haze in the Canadian Arctic. Atmospheric Environment 15:1407-1419.

Bentley, C.R. 1984. The polar regions and climatic change. National Research Council. National Academy Press, Washington, D.C. 59 pp.

Blatter, H. 1987. On the thermal regime of an Arctic valley glacier: a study of White Glacier, Axel Heiberg Island, N.W.T., Canada. Journal of Glaciology 33(114):200-211.

Bradley, R.S. and M.C. Serreze. 1987. Topoclimatic studies of a High Arctic plateau ice cap. Journal of Glaciology 33(114):149-158.

Brown, R.J.E. 1972. Permafrost in the Canadian Arctic Archipelago. Zeitschrift für Geomorphologie Supplement No. 13:102-120.

______. 1977. Permafrost investigations on Truelove Lowland. In: Truelove Lowland, Devon Island, N.W.T.: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 15-26.

Courtin, G.M. and C.L. Labine. 1977. Microclimatological studies on Truelove Lowland. In: Truelove Lowland, Devon Island, N.W.T.: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 73-106.

Green, B.C. 1978. An investigation of thermal fields and secondary circulation in the Canadian western Arctic. M.Sc. thesis. University of Alberta, Edmonton, Alberta.

Hare, F.K. 1968. The Arctic. Quarterly Journal Royal Meteorological Society 94:439-459.

Harington, C.R. 1989. Climate Research Group: McGill University. Climatic Fluctuations & Man 4:145.

Hattersley-Smith, G. 1982. Review of conference proceedings: A Century of Canada's Arctic Islands. Arctic 35(4):565-566.

Koerner, R.M. 1985. Canadian Arctic Islands: glacier mass balance and global sea level. In: Glaciers, Ice Sheets, and Sea Level: Effect of a C02-Induced Climatic Change. Report of a Workshop held in Seattle, Washington (September 13-15, 1984). United States Department of Energy. pp. 145-154.

Koerner, R.M. and D.A. Fisher. 1985. The Devon Island ice core and the glacial record. In: Quaternary Studies on Baffin Island, Baffin Bay and West Greenland. Edited by: J.T. Andrews. Allen and Unwin, Boston. pp. 309-327.

Labine, C.L. 1988. Climatology of the Alexandra Fiord lowland and vicinity. In: Ecology of a Polar Desert Oasis, Alexandra Fiord. Edited by: J. Svoboda and B. Freedman. Captus Press. Toronto.

Marsh, P. and M. Woo. 1981. Snowmelt, glacier melt, and High Arctic streamflow regimes. Canadian Journal of Earth Sciences 18(8):1380-1384.

Maxwell, J.B. 1980. The climate of the Canadian Arctic Islands and adjacent waters. Volume 1. Atmospheric Environment Service. Climatological Studies 30:1-531.

______. 1981. Climatic regions of the Canadian Arctic Islands. Arctic 34(3):225-240.

______. 1987. Climate data for the Canadian Arctic Islands: present and future prospects. In: The Canadian Arctic Islands, Canada's Missing Dimension. Program and Abstracts, Ottawa (November 21-24, 1987). p. 53.

Ohmura, A. 1982A. A historical review of studies of the energy balance of Arctic tundra. Journal of Climatology 2:185-195.

______. 1982B. Climate and energy balance on the Arctic tundra. Journal of Climatology 2:65-84.

Orvig, S. 1981. A century of Arctic meteorology: from discovery to science. In: A Century of Canada's Arctic Islands. Edited by: M. Zaslow. Royal Society of Canada, Ottawa. pp. 131-140.

Serreze, M.C. and R.S. Bradley. 1987. Radiation and cloud observations on a High Arctic plateau ice cap. Journal of Glaciology 33(114):162-168.

Smiley, B. 1987. Historical oceanographic data in the Canadian Arctic Islands: their completeness, reliability and availability. In: The Canadian Arctic Islands, Canada's Missing Dimension, Program and Abstracts, Ottawa (November 21-24, 1987). pp. 46-47.

Smith, M. 1975. Numerical simulation of microclimate and active layer regimes in a High Arctic environment. Indian and Northern Affairs Publication No. QS-8039-000-EE-A1, Ottawa. 29 pp.

Taylor, A. and V. Allen. 1985. Shallow sediment temperatures and thermal properties, Canadian Beaufort Continental Shelf. In: Proceedings 14th Arctic Workshop, Arctic Land-Sea Interaction. Dartmouth, N.S., (November 6-8, 1985). pp. 207-209.

Taylor, A., A. Judge, and M. Burgess. 1983. Abandonment of Arctic wells preserved for subsurface temperature observations: a status report. Energy, Mines and Resources Canada, Earth Physics Branch, Internal Report 83-1:1-40.

Topham, D.R., R.G. Perkin, S.D. Smith, R.J. Anderson, and G. den Hartog. 1983. An investigation of a polynya in the Canadian Archipelago 1, Introduction and Oceanography. Journal of Geophysical Research 88:2888-2899.

Vowinckel, E. and S. Orvig. 1963. Long-wave radiation and total radiation balance at the surface in the Arctic. Arctic Meteorology Research Group, McGill University, Montreal, Publications in Meteorology No. 62:1-53.

Woo, M., P. Marsh, and P. Steer. 1983. Basin water balance in a continuous permafrost environment. In: Permafrost: Fourth International Conference Proceedings. National Academy Press, Washington, D.C. pp. 1407-1411.

Zaslow, M. (editor). 1981. A century of Canada's Arctic Islands. Royal Society of Canada, Ottawa. 538 pp.

THE PLANTS

HIGH ARCTIC ECOSYSTEMS: HOW THEY DEVELOP AND ARE MAINTAINED

L.C. Bliss[1]

Abstract: High Arctic terrestrial ecosystems can be grouped on a landscape basis into polar deserts, polar semideserts, and tundras. The polar deserts support few plant species, and almost no plant production and wildlife. Well-drained substrates prevent water remaining in summer from initiating development of bluegreen algae, cryptogams, and vascular plants. The polar semideserts dominate landscapes in the western Canadian Arctic Islands. These landscapes occur on diverse substrates that support cryptogams into which scattered vascular plants invade. Nitrogen-fixation via bluegreen algae is limited in these ecosystems. Vegetation can support limited numbers of Peary caribou, lemmings and song birds.

Tundra landscapes are the oases of the North. They are dominated by sedge or grass-moss wet meadows. These ecosystems exist only because water remains on the landscape due to blocked drainage by beach ridges or rolling topography. It is here that muskoxen, waterfowl, shorebirds and lemmings abound. Decay of seaweeds and establishment of bluegreen algae on shorelines and in ponds as lands rebounded from the sea, play a significant role in the establishment of these tundra-like ecosystems. This addition of carbon and nitrogen-fixation are of fundamental importance in initiating development of these northern systems.

Résumé: On peut regrouper les écosystèmes terrestres du Haut-Arctique, selon les paysages, en déserts polaires, semi-déserts polaires et toundras. La région des déserts polaires contient fort peu d'espèces de végétaton, et presque pas de faune ni de production de plantes. Les substrats bien drainés empêchent les surplus d'eau d'été de générer la croissance des algues bleu vert, des cryptogames et des plantes vasculaires. Dans les îles de l'Arctique canadien de l'ouest, on trouve surtout des semi-déserts polaires. On rencontre ces paysages lorsque divers substrats alimentent des cryptogames qu'envahissent des plantes vasculaires éparses. La fixation de l'azote par les algues bleu vert est restreinte dans ces écosystèmes. Ce type de végétation ne peut nourrir qu'un nombre limité de caribous de Peary, de lemmings et d'oiseaux chanteurs.

On considère les paysages des toundras comme les oasis du Nord. Ils sont recouverts de prairies à laîches ou de prairies humides d'herbes et mousses. Ces écosystèmes ne peuvent exister que grâce à l'eau qui demeure sur le sol, parce que les cordons littoraux ou la topographie ondulée bloquent le drainage. C'est dans ce milieu qu'abondent les boeufs musqués, les sauvagines, les oiseaux de grève et les lemmings. La décomposition des plantes marines et la formation d'algues bleu vert, sur les côtes et dans les mares quand les terres se relèvent, remplissent un rôle significatif dans la création de systèmes comme la toundra. Cette addition de fixation d'azote et de carbone est d'une importance capitale pour déclencher le processus de développement de ces systèmes nordiques.

INTRODUCTION

The Canadian Arctic Islands constitute a vast region that is diverse in topography, geological age, and climate. It should not be surprising that its terrestrial biology is also diverse considering the above factors and its latitudinal extent (61° to 83°N). This entire region falls within the Arctic, the lands that extend climatically beyond the limit of boreal forest and treeline. Large portions of the Canadian Arctic occur on the Northwest Territories mainland and Yukon Territory, but for the purposes of this paper, they will not be discussed.

Over the years, the Arctic has been divided biogeographically into zones and subzones. Porsild (1951) recognized ice desert, rock desert, and tundra; Polunin (1951) and Young

---

[1] Department of Botany, University of Washington, Seattle, Washington 98195, U.S.A.

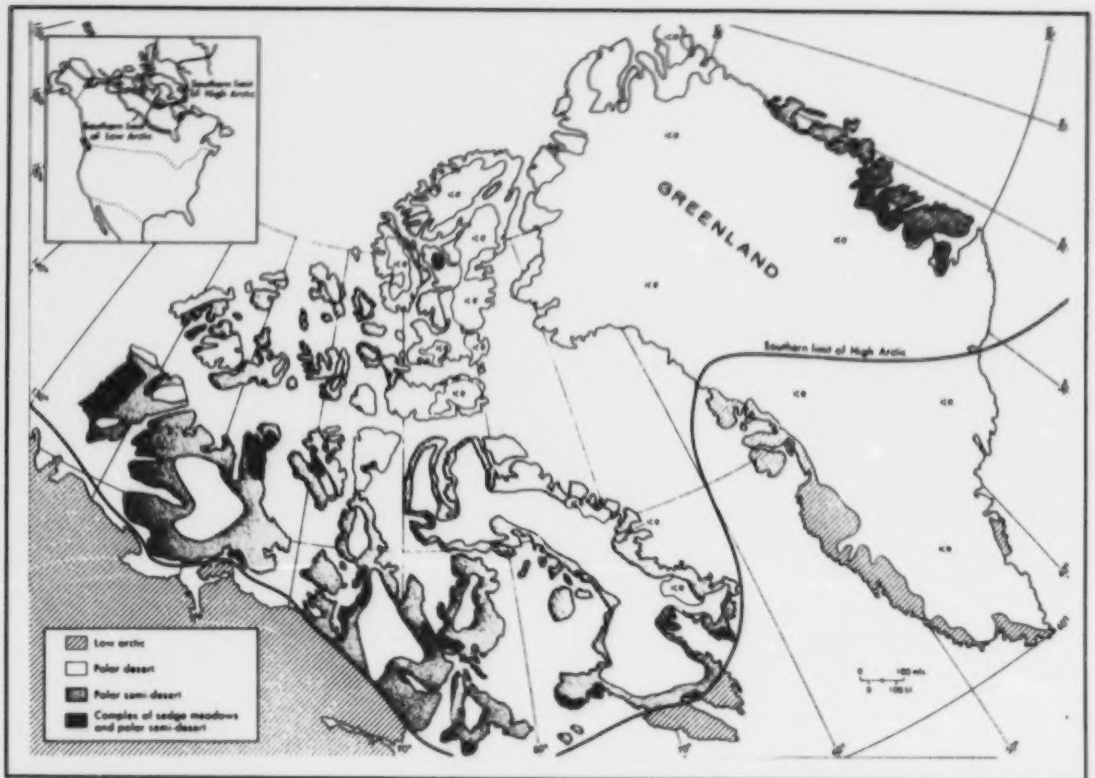

Southern limit of High Arctic
Southern limit of Low Arctic
GREENLAND
Southern limit of High Arctic
ice
▨ Low arctic
☐ Polar desert
▩ Polar semi-desert
■ Complex of sedge meadows and polar semi-desert

FIGURE 1: The High Arctic of Canada and Greenland illustrating the lack of zonation of the major types of vegetation (from Bliss 1977).

(1971) recognized high, mid, and low arctic zones; and Tedrow (1973) divided the Arctic into polar desert, subpolar desert and tundra. The first three authors used floristics to set the boundaries and Tedrow used soils. Based upon field work and general observations at many locations in the Arctic Islands and at several locations on the mainland, I have divided the Arctic into Low and High Arctic using a variety of environmental and biological data (Bliss 1979, 1981, 1988) (Table 1). With the exception of southern Baffin Island, all of the Canadian Arctic Archipelago falls within the High Arctic (Figure 1). As discussed below a mosaic rather than a zonal pattern seems most appropriate to understanding the biological diversity. This is on contrast with Edlund and Alt (1989) who present bioclimatic zones where temperature is the major factor. Temperature measured as degree-days is very important, but so are water and nutrient status of the soils.

TABLE 1: GENERAL COMPARISON OF ENVIRONMENTAL AND BIOLOGICAL CHARACTERISTICS OF THE LOW AND HIGH ARCTIC WITHIN CANADA.

CHARACTERISTICS	LOW ARCTIC	HIGH ARCTIC
Environmental		
Length of growing-season (months)	3 - 4	1.5 - 2.5
Mean July temperature (°C)	8 to 12	3 to 8
Mean January temperature (°C)	-20 to -28	-25 to -35
Annual mean temperature (°C)	-9 to -12	-12 to -19
Accumulated degree-days above 0°C	600 - 1400	150 - 600
Active-layer depth (cm)		
fine textured soils	30 - 50	30 - 50
coarse-textured soils	100 - 300	70 - 150
Soil pH	mostly 5 to 6.5	mostly 6 to 8
Organic Layer (cm)		
Lowlands	50 - 300+	5 - 50
Uplands	2 - 20	0 - 1
Biological		
Vascular plants (numbers of species)		
Per region or island	150 - 400	40 - 140
Alaska and Canada	700	350+
Plant-cover (%)		
Tundra	80 - 100	80 - 100
Polar semidesert	20 - 80	20 - 80
Polar desert	1 - 5	1 - 5
Plant-height (cm)		
Shrubs	10 - 500	5 - 100
Herbs	5 - 50	2 - 20
Land mammals (numbers of species)	10 - 15	1 - 8
Large mammals	Barren-ground caribou, muskox, moose	Peary caribou, muskox
Nesting birds (numbers of species)	30 - 60	0 - 20
Fishes (numbers of species)	15 - 21	3 - 7

The objectives of this paper are to: (1) present the landscape pattern of biological systems or ecosystems; (2) explain why they occur where they do; (3) suggest how they developed following deglaciation; and (4) discuss their ability to support wildlife.

PHYSICAL ENVIRONMENT

Climate

The macroclimate of the High Arctic is characterized by continuous darkness in mid-winter, with a cover of snow and ice for 9 to 10.5 months, and by continuous light in summer with its growing season of only 1.5 to 2.5 months. In winter a large semi-permanent system of high pressure blankets the Arctic with its very cold, dry air. In summer the arctic high pressure system is weaker with its southern limit paralleling the arctic-boreal forest boundary about 50% of the time (Bryson 1966). Low pressure systems in the Gulf of Alaska and between Baffin Island and Greenland bring increased precipitation to the southern and eastern portions of the High Arctic in summer.

Annual net solar radiation averages 400-600 MJ/m^2/yr over the southern Arctic Islands, dropping to <100 MJ/m^2/yr in northern Ellesmere Island (Maxwell 1981). Solar radiation and the resultant temperature of soils and air greatly influence the development of vegetation. Except for lands above 200-300 m, most snow disappears in mid to late June, by direct evaporation (sublimation) and by melt. Mean monthly temperature in June is often 1° to 2°C at Sachs Harbour (72°N), Cambridge Bay (71°N), Clyde (70°N) and Eureka (80°N). Many other High Arctic stations have mean monthly temperatures near 0°C in June, but July, the warmest month, averages 3° to 8°C at most stations (Environment Canada 1982; Maxwell 1981). Annual precipitation is highly variable over this region, averaging from 200-680 mm along the coast of Baffin Island to 100-150 mm over much of the central and western High Arctic, and to a low of 60 mm at Eureka, Ellesmere Island. Maxwell (1981) has divided the Arctic Archipelago into five climatic regions. Throughout these regions net annual solar radiation and precipitation are more variable than temperature.

Permafrost

An important physical factor that influences biological activity is the presence of permafrost and the shallow layer of thawed soil that forms in summer - the active layer. Permafrost is defined as areas of soil, rock and seafloor where the temperature remains below 0°C for two or more years. All of the Arctic is underlain by permafrost, and within the Arctic Islands it is generally 400 to 650+ m thick. Not all permafrost has a high ice content, usually represented by massive ice-lenses and ice-wedges. These features are more limited in the High Arctic. Due to freeze-thaw cycles and the differential sorting of fine and coarse materials, sorted and non-sorted circles and stripes, raised and depressed-centre polygons, earth-hummocks and solifluction-slopes and steps are often present. Raised-centre and depressed-centre polygons are found in lowlands with fine-textured mineral and peat soils. Stone nets (sorted polygons) and stripes are typical of uplands. These patterned-ground features (Washburn 1956, 1980) influence the distribution of plants and the development of soils.

Some surface features in the High Arctic result from desiccation cracks rather than from ice formation. Many of these polygonal patterns, are only 10-30 cm across compared with the sorted (rock-edged) and non-sorted polygons that are generally 1-5 m across. Soil-hummocks probably result from intense soil churning during spring and fall freezing cycles, although some hummocks result from growth and accumulation of mosses and soil algae. Needle-ice is another important feature of finer-textured soils. The ice forms in spring and fall, but more commonly in the fall, when the soils are wet and relatively warm compared to the cold air at and above the soil surface. Needle-ice lifts the surface soils 1-5 cm and can pull out seedlings and young plants. This greatly reduces plant establishment in some soils. The grasses *Phippsia algida*, *Puccinellia angustata*, and *P. vaginata* have roots that curl. These species appear better adapted to growing in these more active, bare soils (Bell and Bliss 1978; Grulke and Bliss 1988; Sohlberg and Bliss 1984).

The shallow active layer (10-30 cm) of lowland, wet areas with their abundance of bryophytes, sedges, and some grasses greatly limit the vertical development of roots. Better-drained soils of uplands, slopes, and coarse-textured sands and gravels thaw to a greater depth (50-100+ cm) and are warmer in summer. Consequently plant roots may penetrate to deeper levels, and lemmings can develop tunnel-networks for summer. In winter they live in nests constructed of grasses and sedges on the soil surface, but sites where winter snow is 50 to 150+ cm deep provide more insulation from the very low air temperatures (-30° to -60°C).

Soils

Plant communities and soils are interrelated in the High Arctic, as they are within the coniferous forest and grassland biomes to the south. However within the High Arctic, soil-forming processes are greatly reduced. Shallow peats (Fibrisols), 5-20 cm thick, overlay gleysolic soils in lowlands with their sedge moss or grass-moss communities. These soils are generally neutral to slightly acid and they usually have higher levels of nitrogen. On rolling lands with polar semidesert vegetation of cushion plant-cryptogam or cryptogam-herb communities, soils are Brunisols to Regosols on the former and Regosolic Static Cryosols on the latter sites. Within the barren polar deserts, soils have no horizon development, are neutral to slightly alkaline and usually base-saturated. Nitrogen and phosphorus are very low in these Gleysols and Regosols. Free carbonates are sometimes released from sedimentary rocks or recently uplifted marine sediments nearer to coasts. In these habitats, magnesium and calcium salts effervesce on soil surfaces during brief warm, dry periods in summer. Halophytic species are found in these sites, as well as in shallow coastal lagoons with extremely depauperate salt marshes (Jeffries 1977). Details of High Arctic soils can be found in Tedrow (1977).

EVOLUTION OF HIGH ARCTIC ECOSYSTEMS

Arctic ecosystems are young in terms of geological time. The Beaufort Formation from Banks Island (71°N) to Meighen Island (80°N) contains fossils of mixed coniferous-deciduous forests that date from mid-Miocene to Pliocene age (8-5 million years ago) (Hills *et al.* 1974; see Matthews *et al.*, this volume). Tundra may have occurred farther north and at higher elevations on Axel Heiberg and Ellesmere islands. Plants and animals that now occupy the Arctic are believed to have evolved on the highlands of central Asia and the mountains of northwestern Asia and northern North America (Hoffman and Taber 1967; Yurtsev 1972; Packer 1974). From these centres of origin, plants and animals spread north and across Beringia (the former land-connection between eastern Siberia and Alaska) to enrich the biota of both continents.

Although arctic ecosystems had their origin several millions of years ago, the present pattern of ecosystems with their limited species-richness have been present only since Wisconsin ice retreat. Thus for lowland areas where isostatic rebound of the land has resulted in sedge-moss, grass-moss tundra systems, or polar semidesert systems of cushion plants-cryptogams and cryptogams-herbs, the ecosystems have been developing for less than 10,000-11,000 years (Bryson *et al.* 1965). On rolling uplands of 50-150 m elevation, the landscapes are probably only 3,000 to 6,000 years old, whereas the lands above 200-300 m have been ice-free for less than 3,000 years in the eastern islands. Many of the most barren lands may have been covered in snow and ice during the Little Ice Age, so colonization by cryptogams and vascular plants is limited to the last 130-430 years (Svoboda 1982).

HIGH ARCTIC ECOSYSTEMS, THEIR STRUCTURE AND FUNCTION

Polar Desert Ecosystems

Polar Barrens

There are thousands of square kilometres (some 44% of the total landscape), especially in the Queen Elizabeth Islands, that are essentially devoid of plants, birds, and mammals. These landscapes occur from near sea level (10-20 m) to uplands above 200-300 m. The basic controls involve the geological substrate, as this influences soil development and retention of water, as well as the length of the snow-free season (1-1.5 months). A thin veneer of rocks often covers the surface, reducing the amount of bare soil where seedlings could establish (Figure 2). Other areas have at least 30-50% bare soil relative to surface rocks. The medium-grained sands to clay-loams are very wet following snow melt, yet are often very dry in the upper 1-3 cm by mid to late July, thus making seedling establishment more difficult.

Woody species are absent from these barren landscapes. Only small rosettes of *Draba*, *Minuartia* and *Saxifraga*, cushion plants of *Saxifraga* or mat-forming species including

Puccinellia occur as widely-spaced individuals. In a study of 23 sites on six islands, only 17 species of vascular plants and 14 species of lichens and mosses were found. The average number of species at a site was nine. Vascular-plant cover averaged 1.8% and cryptogams only 0.7%. The rest of the surface was bare soil, frost-shattered rocks, and pebbles. The most common vascular plants included *Draba corymbosa, D. subcapitata, Papaver radicatum, Minuartia rubella, Puccinellia angustata*, and *Saxifraga oppositifolia*. The most common mosses were *Tortula ruralis* and *Hypnum bambergeri* and the lichens *Thamnolia subuliformis, Dermatocarpon hepaticum*, and *Lecanora epibryon* (Bliss *et al.* 1984).

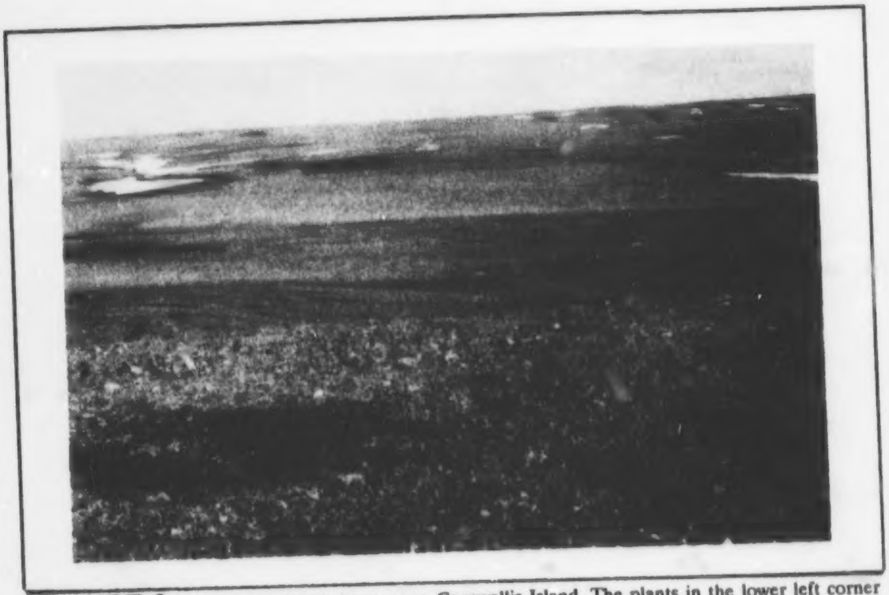


FIGURE 2: **The polar desert barrens on Cornwallis Island. The plants in the lower left corner are on an old lemming mound. The species include Papaver radicatum, Saxifraga cernua and Festuca brachyphylla.**

Snowflush

The only significant plant cover within the polar barrens is found in the meltwater channels below large snowbanks. These snowflush communities are very conspicuous, yet they occupy only 3-5% of the landscape. Many more species were sampled in these habitats with meltwater present all summer (30 species of vascular plants and 27 species of mosses and lichens) in the 12 sites sampled on three islands. Plant cover was also much greater within the snowflush communities; 18.5% bryophytes, 9% vascular plants, and 8% lichens. Vascular plants occur on moss-mats, usually as scattered individuals (Figure 3). In some sites the graminoids *Eriophorum triste* or *Alopecurus alpinus* were the most important species; in others *Saxifraga oppositifolia, Papaver radicatum, Draba corymbosa, Minuartia rubella*, and *Phippsia algida* dominated as scattered plants. Bluegreen algae (Cyanobacteria) were

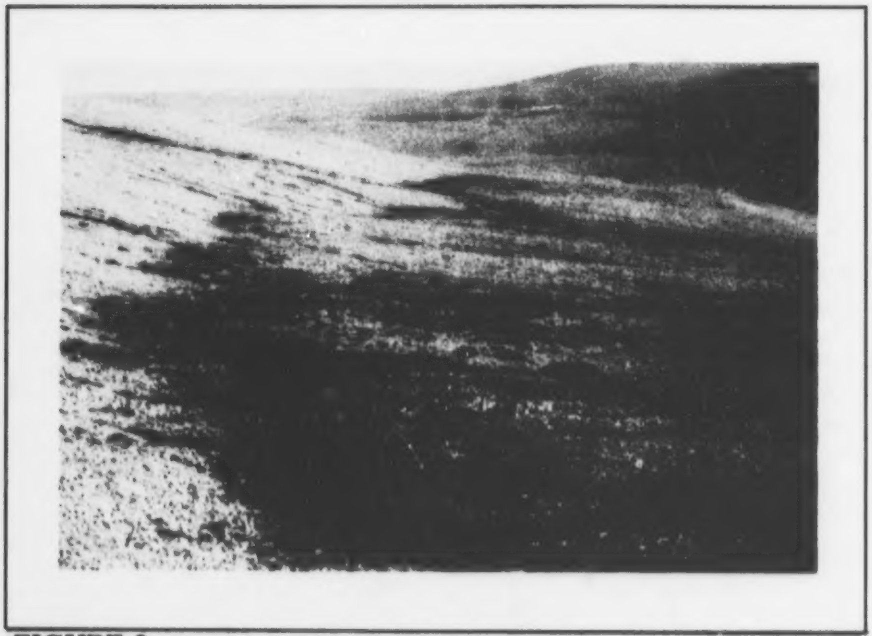


FIGURE 3: Snowflush site within a polar desert barren on Cornwallis Island. Within the moss-mats are scattered plants of Alopecurus alpinus, Phippsia algida, Saxifraga cernua and Papaver radicatum.

always found in the moss mats, so the ability to fix nitrogen is present in these habitats. The stripes and polygonal troughs contain the mosses *Orthothecium chryseum, Ditrichum flexicaule, Drepanocladus revulens, Schistidium holmenianum*, and *Hypnum bambergeri*. The lichens *Dermatocarpon hepaticum* and *Lecanora epibryon* were the only ones of importance. With the exception of *Phippsia algida* and *Alopecurus alpinus*, almost all vascular plants were found on the moss-mats, microsites that are always moist and contain more nutrients. *Salix arctica* was found at only one site, a steep slope facing south, and therefore a warmer site.

Within these barren lands, collared lemming colonies are rare, and most colonies observed were inactive. Due to manuring, plants were always abundant on these slightly-elevated sites. They commonly include *Papaver radicatum, Alopecurus alpinus, Poa arctica, Saxifraga cernua*, and *Cerastium alpinum*.

Polar Semidesert Ecosystems

In addition to the barren polar deserts and lands covered with ice caps and glaciers (10% of the total area), there are vast areas of land that have 5% to 25% cover of vascular plants. Lichens and bryophytes contribute an additional 20% to 80% cover in many areas. Vascular plants are smaller in size (3-10 cm) than the same species (10-30 cm) in the Low Arctic of mainland Canada and northern Alaska, the result of a more severe environment. Root systems of these plants are also smaller. The two major community types are cushion plant-cryptogam and cryptogam-herb. Polar semideserts cover about 40% of the lands of the Arctic Islands.

Cushion Plant-Cryptogam

Large mats of *Dryas integrifolia* with associated species of *Salix arctica, Saxifraga oppositifolia, S. caespitosa, S. cernua, Papaver radicatum, Draba corymbosa*, and several species of *Stellaria* and *Minuartia* occupy rolling uplands and gravelly raised-beaches (Figure 4). Scattered plants of *Carex rupestris, C. nardina, Alopecurus alpinus*, and *Luzula confusa* are also present. The common lichens *Thamnolia subuliformis, Dermatocarpon hepaticum, Lecanora epibryon*, and the mosses *Hypnum bambergeri* and *Tortula ruralis* generally add 30% to 60% cover. Communities of this general type have been described by Brassard and Longton (1970), Svoboda (1977), Reznicek and Svoboda (1982), Sheard and Geale (1983), and Bliss *et al.* (1984).

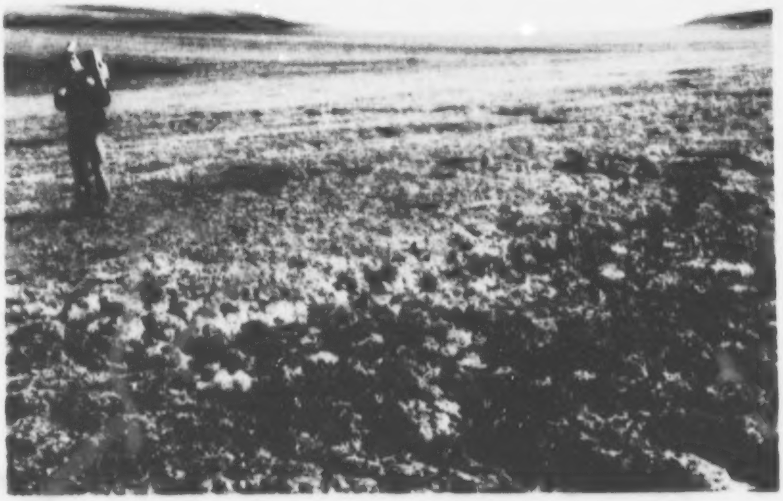


FIGURE 4: Rolling upland near Thomson River, northern Banks Island, within a cushion plant - cryptogam plant community. The dominant cushion-plants are Dryas integrifolia and Salix arctica with smaller amounts of Carex nardina, Oxytropis arctica, and Parrya arctica.

Peary caribou, collared lemming, ptarmigan, Snow Bunting, Black-bellied Plover and Baird's Sandpiper are commonly found in these lands, although in low numbers because of the limited forage and invertebrates to feed upon. This community and the cryptogam-herb community provide important habitat for caribou.

Cryptogam-Herb

Communities of lichens and mosses with scattered clumps of herbaceous plants and graminoids often cover the rolling hills on the western Queen Elizabeth Islands (Figure 5). The soils are sandy to clay-loam in texture. Vascular plants generally contribute 5% to 20% cover and cryptogams 50% to 80% cover. *Papaver radicatum, Cerastium alpinum, Draba corymbosa, Juncus albescens,* and three to five species of *Saxifraga* are the most common forbs. The dominant graminoids include *Alopecurus alpinus, Luzula confusa,* and *L. nivalis.* Some of the more common mosses include *Ditrichum flexicaule, Pogonatum alpinum, Polytrichum juniperinum, Aulacomnium turgidum, Rhacomitrium sudeticum, Tomenthypnum nitens,* and *Schistidium holmenianum.* In clay-soils that are wetter in summer, the liverwort *Gymnomitrion corallioides* is often abundant. Common species of lichens include *Lecanora epibryon, Lepraria neglecta, Dermatocarpon hepaticum, Cladonia delisei, C. gracilis, Cetraria cucullata, C. nivalis,* and *Dactylina ramulosa* (Bliss and Svoboda 1984). There is often a thin, black crust of lichens, mosses, and bluegreen algae called "patena". We believe this crust is important in fixing nitrogen in soils that are low in nitrogen and phosphorus.

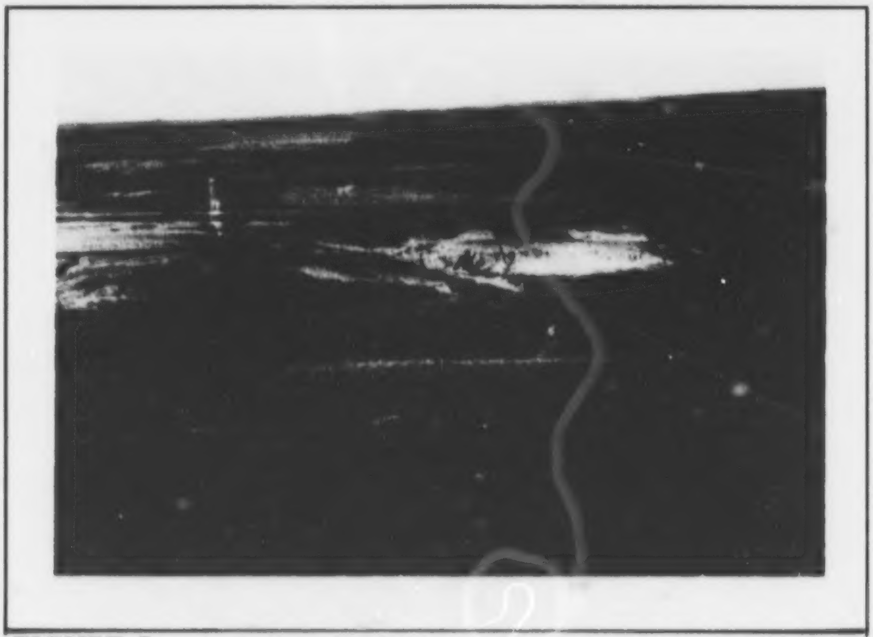


FIGURE 5: A cryptogam-herb community on King Christian Island. The dominant vascular plants are *Alopecurus alpinus*, *Luzula confusa*, *Draba bellii*, *Papaver radicatum* and several species of *Saxifraga*. Mosses and crustose lichens are also abundant.

Seedlings of vascular plants are found on a variety of microsites, but their survival to adults is much more common on moss-mats and to a lesser extent lichen surfaces and desiccation-cracks where mosses are more abundant (Sohlberg and Bliss 1984). Crustose lichens are not as effective as moss-mats in reducing evaporation from moist surfaces.

Lichens are more effective in reducing evaporation when surface soils are dry (Addison and Bliss 1980). This helps to explain why seed germination and seedling survival is not abundant in these communities (Bell and Bliss 1980). Seeds are transported over the snow and, in general, the number of seeds trapped in the lower layers of snow in spring reflects plant density and seed production within these cryptogam-herb communities (Grulke and Bliss 1983).

Data on plant/water relations of several species also help explain their distribution patterns. *Luzula confusa* is confined to moist soils, and is not found in the dry soils (upper 3-5 cm) of exposed slopes and ridges within the cushion plant-cryptogam and cryptogam-herb plant communities. Nor is this species found in the barren polar deserts. Rates of photosynthesis drop significantly with increased leaf water potentials of -0.7 MPa (Addison and Bliss 1984). In contrast, *Phippsia algida* and *Puccinellia vaginata* are not severely drought-affected at leaf water potentials of less than -2.0 MPa (Grulke and Bliss 1988). Both species grow in bare soils, and *Phippsia* also is found within mats of cryptogam-herb communities.

Mammals and birds occur in these polar semidesert landscapes, but species are few and densities are low. Collared lemmings (*Dicrostonyx groenlandicus*) occur as sparse colonies. Many of the "lemming gardens" observed are abandoned in a given summer. No studies have been conducted on lemming densities in the central and western islands. At Truelove Lowland on Devon Island, lemming densities averaged 1.8/ha on the cushion-plant communities of beach-ridges and 3.3/ha in the lusher vegetation of ice-core polygons. These animals consumed mostly *Dryas integrifolia*, *Salix arctica*, and *Saxifraga oppositifolia* (Fuller *et al.* 1977). In the northwestern islands where rosette-forbs and tufted-graminoids are more common (cryptogam-herb plant communities), I have observed that a greater mixture of species is consumed including *Alopecurus alpinus* and *Poa arctica*.

Muskoxen (*Ovibos moschatus*) are seldom observed in polar semideserts of the western Queen Elizabeth Islands because of limited forage. However Peary caribou (*Rangifer tarandus pearyi*) occur in small numbers in the northwestern islands, but are more common on Melville, Banks, Victoria, and Prince of Wales islands. These animals are most commonly observed in the rolling uplands dominated by cushion-plant communities.

Arctic fox (*Alopex lagopus*) and arctic wolf (*Canis lupus*) are seldom found in these landscapes, presumably because of the lack of food to support them. Arctic hares (*Lepus* *arcticus*) are rare unless *Salix arctica*, their preferred food, is abundant. Feeding observations on the Truelove Lowland, Devon island showed that *Salix arctica* and *Pedicularis* spp. were the preferred foods (Riewe and Speller 1972). The largest hare populations are on Ellesmere and Axel Heiberg islands where arctic willow is abundant.

Birds are seldom observed in the Queen Elizabeth Islands unless ponds and lakes are present. The most common species with breeding populations in uplands include: Snow Bunting (*Plectrophenax nivalis*), Arctic Tern (*Sterna paradisaea*), Baird's Sandpiper (*Erolia bairdii*), and Black-bellied Plover (*Squatarola squatarola*). Long-tailed jaeger (*Stercorarius longicaudus*), and Rock Ptarmigan (*Lagopus mutus*), are present but in low numbers. Although these species nest in upland sites or rock outcrops with cushion-plants, dwarf-heath or cryptogam-herb communities, most species feed extensively in graminoid-moss meadows where insects are more common (Pattie 1977, Freedman and Svoboda 1982). Breeding-bird densities are low within the High Arctic (2 to 33 pairs/100 ha) compared with the Low Arctic of mainland Canada (60 to 200 pairs/100 ha) (see Freedman and Svoboda 1982). In more barren landscapes with mostly polar-semidesert vegetation, limited data indicate 2 to 5 pairs/100 ha is near the upper end of the density scale.

Tundra Ecosystems

Biologically the most important ecosystems in the Arctic Islands are the scattered lowlands often called the oases of the High Arctic (Bliss 1977, Svoboda and Freedman 1980, 1989). These heterogenous landscapes contain: lush sedges, grasses, and mosses; ponds and small lakes; and often beach-ridges and other sites that are better drained with cushion plant-cryptogam and dwarf shrub-heath communities. Wetland ecosystems occupy only 1-2% of the landscape in the Queen Elizabeth Islands, but are more common in the southern islands (Table 2). In addition to these graminoid-moss communities there are limited areas of dwarf shrub-heath, cottongrass tussock, and tall or medium shrub communities. It is these communities, although very limited in extent, that have enabled some authors to refer to these lands as Mid or even Low Arctic (Ritchie *et al.* 1987). Because most of the land is covered with cushion plant-cryptogam vegetation and polar desert, and since bird, fish, and mammal faunas are comparable to those of the northern islands, it seems only appropriate to consider all of the Arctic Archipelago as High Arctic.

TABLE 2: ESTIMATED LANDSCAPE AREAS WITHIN THE CANADIAN ARCTIC ARCHIPELAGO.

LANDSCAPE-TYPE AND PERCENTAGE				
REGION	MEADOW	POLAR SEMIDESERT	POLAR DESERT	ICE
Queen Elizabeth Islands	1	25	49	25
Southern islands	8	47	43	2
Arctic Archipelago	6	40	44	10

Graminoid-moss Tundra

The only common tundra-like vegetation in the Arctic Islands is the wet sedge-moss or wet grass-moss type (Figure 6). In the southern and eastern islands, communities of *Carex stans* and *C. membranaceae* predominate with lesser amounts of *Eriophorum triste, E. scheuchzeri, Dupontia fisheri*, and *Alopecurus alpinus*. There are very few associated forb species. *Salix arctica* and *Dryas integrifolia* occur in microsites that are better drained, such as moss-mounds and rocky areas. These communities occur only where drainage is impeded along river terraces, small valleys, and coastal lowlands with gravelly beach-ridges (relicts of old shoreline features). Communities with these characteristics have been described from Banks and Victoria islands (Bliss and Svoboda, unpublished manuscript), Devon Island (Muc 1977), Ellesmere Island (Freedman *et al.* 1983), and Bathurst Island (Sheard and Geal 1983). In the northwestern islands the sedges are generally absent, replaced by *Dupontia fisheri* (Figure 7), and to a lesser degree *Alopecurus alpinus* with *Pleuropogon sabinei* in shallow ponds (Bird 1975, Bliss and Svoboda 1984). Bryophytes are abundant in these habitats including *Tomenthypnum nitens, Campylium arcticum, Orthothecium chryseum, Ditrichum flexicaule*, and *Cinclidium arcticum*. Lichens are sparse but the cyanobacteria *Nostoc commune* is very common and is important in fixing nitrogen.

Muskox feed in these wet meadows throughout the year, but the meadows become most critical for winter grazing. During the long, cold winter when all surfaces are covered with snow and ice, these localized "hot spots" or "oases" with their complex of sedges and grasses are essential forage habitat (Hubert 1977). Feeding cycles are 4-6 hours in summer but a

FIGURE 6: Sedge-moss meadow on the Truelove Lowland, Devon Island. Carex stans is the dominant vascular plant with a few scattered Pedicularis sudetica and Salix arctica.

FIGURE 7: Small meadow of Dupontia fisheri near the Hoodoo River, Ellef Ringnes Island.

bit shorter in winter. On average they remove 7% of the aboveground forage within sedge-moss meadows per year. However, in select meadows where they concentrate in winter, 15-20% of the forage is removed. Summer forage has a high protein-content (17-21%) and although it is much lower in winter (6-9%), the protein levels are higher than in many temperate graminoids in winter. Assimilation efficiency of these animals on the Truelove Lowland, Devon Island was estimated to be 84% in summer and 66% in winter, important adaptations to these severe arctic environments (Hubert 1977).

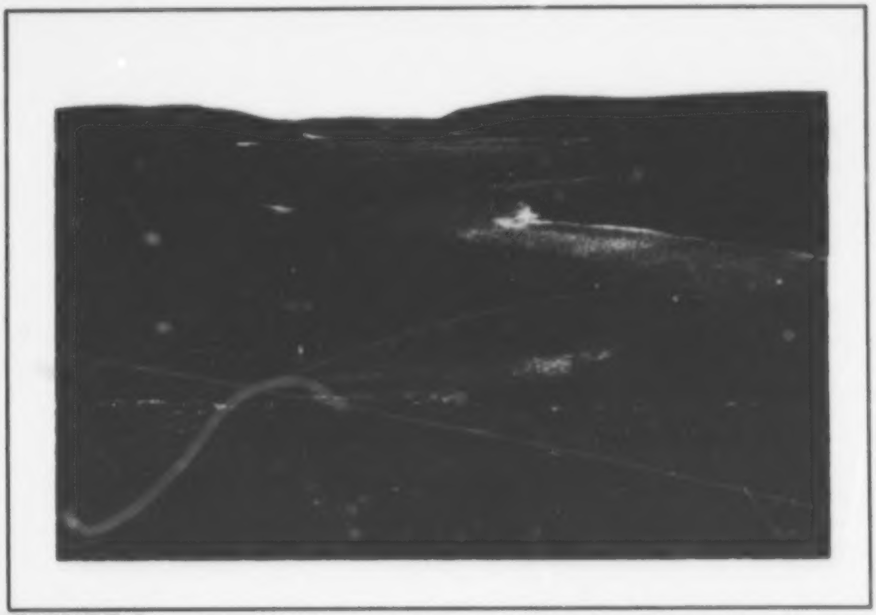


FIGURE 8: Sedge-moss meadows along the Thomson River, Banks Island, with cushion plant-cryptogam community in the uplands (foreground).

In the eastern and southern islands and on Melville Island relatively large areas exist where there is a mosaic of wet sedge-moss meadows and rolling uplands with cushion plant-cryptogam or less commonly, cryptogam-herb communities (Figure 8). There appears to be little competition for food or space between Peary caribou, that generally occupy the uplands, and muskoxen in the lowlands (Parker and Ross 1976; Thomas and Edmonds 1984; Gray 1987). Caribou graze on the upland graminoids (grasses, sedges, rushes), arctic willow, lichens, and flower-stalks of a variety of forbs but especially *Papaver radicatum* (Wilkinson *et al.* 1976; Thomas and Kroeger 1980). In contrast, muskoxen feed primarily in lowlands both summer and winter, based upon rumen samples (Wilkinson *et al.* 1976). In summer muskoxen also feed in more sparsely-vegetated landscapes (Hubert 1977; Gray 1987).

Ponds and lakes are always associated with graminoid-moss meadows, and it is these habitats in which we find shorebirds and waterfowl. Red-throated Loons (*Gavia stellata*), Oldsquaw (*Clangula hyemalis*), Common Eider (*Somateria mollissima*), King Eider (*S. spectabilis*), and Arctic Tern (*Sterna paradisaea*) nest near these water bodies. Parasitic Jaeger (*Stercorarius parasiticus*), Long-tailed Jaeger (*Stercorarius longicaudus*), White-rumped Sandpipers (*Erolia fusicollis*), and Lapland Longspurs (*Calcarius lapponicus*) commonly nest in these wet meadows on the Truelove Lowland (Pattie 1977). Many of these species also nest in comparable habitat farther north on Ellesmere Island (Freedman and Svoboda 1982; Savile and Oliver 1964). Snow Buntings (*Plectrophenax nivalis*) are usually the most abundant species in these lowlands (Pattie 1977; Freedman and Svoboda 1982).

The most common predators, arctic fox, jaegers, and Snowy Owls (*Nyctea scandiaca*) are commonly found in these lowlands where there is a greater abundance of lemmings and nesting birds.

Dwarf Shrub-Heath Tundra

Heath communities are best developed on southern Baffin Island, although small areas of heath are found on Victoria Island (Polunin 1948; Bliss and Svoboda, unpublished manuscript). *Cassiope tetragona* predominates, but limited amounts of *Vaccinium uliginosum* spp. *microphyllum*, *Salix herbacea*, *S. arctica*, *Luzula nivalis* and *L. confusa* also occur. On Devon and Ellesmere islands, small areas of heath are found, usually with *Cassiope tetragona*, *Dryas integrifolia*, and *Salix arctica* dominating (Brassard and Longton 1970, Bliss *et al.* 1977, Freedman *et al.* 1983). These communities generally occur in and near rocky areas where snow remains until early July. Mosses and lichens are abundant at these sites.

Other Tundra Communities

There are small areas of cottongrass tussock and tall shrub-tundra in the southern islands. These communities are closely related to those of the Low Arctic, but here the species richness is low and shrub-height is greatly reduced. Along rivers and near lakes and ponds are low thickets (0.5-1.5 m) of *Salix alaxensis*, *S. pulchra*, and *S. lanata* (Kuc 1974; personal observation).

Salt-marshes occur along a few coastal areas where stable surfaces of sand, silt, or even bedrock occur. *Puccinellia phryganodes* dominates with lesser amounts of *Carex ursina*, *Cochlearia officinallis*, and *Stellaria humifusa* (Jeffries 1977; Thannheiser 1975). These coastal brackish marshes are always small in area due to the limited tidal amplitude, shore-ice that remains into July, and a general lack of sands and silts favourable for plant establishment.

PRODUCTIVITY COMPARISON OF HIGH ARCTIC ECOSYSTEMS

From the above discussion, evidently only those lands with more abundant vegetation can support a diversity of wildlife in the High Arctic. Although we have no detailed data for the polar barren and cryptogam-herb ecosystems, plant-production data give some idea of their ability to support birds and mammals. Data from Truelove Lowland clearly show that the sedge-moss meadows are much more productive than the cushion plant-cryptogam systems on the gravelly raised-beach ridges (Table 3). It is these latter communities that are more common in the southern and eastern Arctic Islands and over extensive areas of Melville Island.

Large Herbivores - Peary Caribou and Muskox

Peary caribou (*Rangifer tarandus pearyi*) occur throughout the islands with the exception of Baffin Island where barren-ground caribou (*R. tarandus groenlandicus*), typical of the Arctic mainland occurs (Banfield 1974). Muskoxen (*Ovibos moschatus*) are not found on Baffin Island and only in very low numbers, if at all, in the most northwestern islands (Ellef Ringnes, King Christian, Amund Ringnes, Brock, Borden, Mackenzie King, Prince Patrick and Lougheed). Populations are largest on those islands that have a great amount of forage, mostly wet graminoid-moss meadows and patches of arctic willow, as discussed earlier.

Accurate estimates for the number of Peary caribou and muskoxen are difficult to obtain, and their numbers fluctuate widely. An aerial survey in 1961 estimated 24,300 caribou in the western Queen Elizabeth Islands (Tener 1963), but Miller (1978) reported only 2,700 animals in 1974. This latter estimate followed the severe winter of 1973-1974, when large numbers of caribou and muskoxen died due to icings at the soil-surface, which can eliminate foraging over large areas. Deep winter snow (>50 cm) can also be an important cause of population crashes, by preventing successful cratering for vegetation by muskoxen (Hubert 1977). The general decline in population from 1961-1973 appears to

TABLE 3: ESTIMATED ABOVEGROUND PHYTOMASS, NET ANNUAL PLANT PRODUCTION (NPP), AND PERCENT FORAGE CONSUMED BY CARIBOU AND MUSKOXEN IN HIGH ARCTIC ECOSYSTEMS.

PLANT COMMUNITY	AREA (km)^2	ABOVEGROUND PHYTOMASS (t/km^2)	NET PLANT PRODUCTION (t/km^2)	TOTAL NPP ON 1000 KM^2 (t/km^2)	NPP CONSUMED (%)	FORAGE CONSUMED on 1000 km^2 (t/km^2)
SOUTHERN AND EASTERN ISLANDS						
Low-shrub	5	300- 500	70-100	350- 500	10	35- 50
Wet sedge-moss	60	700-1,000	50- 75	3,000- 4,500	7	210-315
Cushion-plant	280	100- 750	15- 50	4,200-14,000	3	126-420
Polar barrens	655	1- 100	1- 2	------	-----	-----
Total	1000	1,101-2,350	135-226	7,550-19,000	-----	371-785
NORTHWESTERN ISLANDS						
Cryptogam-herb	550	200-2,000	5- 10	2,750- 5,500	2	55-110
Wetgrass-moss	30	500- 800	20- 30	600- 900	5	30- 45
Polar barrens	420	1- 100	1- 2	------	-----	-----
Total	1000	701-2,900	26- 42	3,350-6,400	-----	85-155

TABLE 4: DAILY FORAGE CONSUMPTION AND MEAN BODY WEIGHT FOR ARCTIC HERBIVORES.

SPECIES	DAILY FORAGE CONSUMPTION (% LIVE WT)		MEAN VALUE USED (%)	MEAN BODY WT (kg)	REFERENCES
	Summer	Winter			
Peary caribou	-------	-------	2.2	50	------------
Muskox	1.7-2.2	1.3-1.7	2.2	180	Hubert (1977)

have resulted from low birth-rates and calf-survival (Parker *et al.* 1975). Predation by wolves and polar bears appears to be a minor cause of death, especially for muskoxen (Gray 1987).

Muskox numbers also fluctuate in relation to winter weather and forage-availability. Hubert (1977) reported a density of 0.9 animals/km^2 on five lowlands in northeastern Devon Island. Lower numbers have been sighted on aerial surveys in the mid-1980s (Arctic Institute of North America, unpublished data; see Pattie, this volume). Aerial surveys in 1979-1980 resulted in estimates of 19,300 muskoxen on Banks Island (Vincent and Gunn 1981), but only 12,000 animals on Banks and Victoria islands were estimated in 1980 by Jakimchuk and Carruthers as reported by Gunn (1984). Accurate surveys are difficult to achieve over such large areas, especially when most muskoxen and caribou occur in the limited areas of more lush vegetation.

Landscapes and Estimated Herbivore Carrying-Capacity

To calculate animal carrying-capacity and density, different modelling approaches have been used. Some use ecological efficiencies of the herbivores. Others have used animal density as the driving force. The larger database on plant phytomass and plant production and daily food requirements of large herbivores is believed to give more accurate estimates. The latter approach has been used to estimate past animal density in the Alaskan part of Beringia 25,000 to 11,000 years ago (Bliss and Richards 1982), the Bluefish River area in the Yukon 15,000 to 12,000 years ago (Ritchie 1984), and for modern arctic large mammals of North America (Bliss 1986).

Here I have used estimates of aboveground phytomass, net annual plant production (aboveground), average forage-utilization rates (daily) for a ruminant (2.2%/d of mean body weight), and assumed plant communities on the landscape.

Two major landscapes are considered; one in the southern (Banks, Victoria, Prince of Wales, Baffin) and northeastern Arctic Islands (Axel Heiberg, Ellesmere, Devon), and a second one in the northwestern islands. Peary caribou and muskoxen browse the low shrubs (only Banks, Victoria, Baffin islands) and graze the graminoid-moss, cushion plant-cryptogam and cryptogam-herb communities, but at different intensities. For each landscape I have assumed 1000 km^2 with representative patterns of plant communities and assumed foraging-patterns of the two herbivores (Figure 9). Low willow shrubs (1-1.5 m) are assumed to grow only along streams, rivers, and at a few wet sites in the southern islands. These are

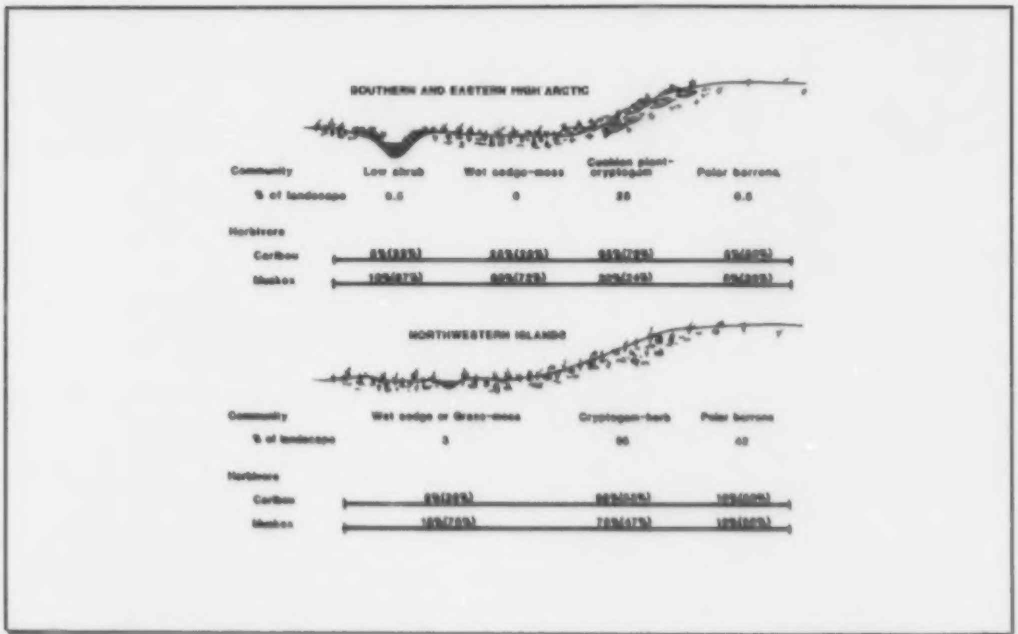

SOUTHERN AND EASTERN HIGH ARCTIC
Community
Low shrub
Wet sedge-moss
Cushion plant-cryptogam
Polar barrens
% of landscape
Herbivore
Caribou
Muskox
NORTHWESTERN ISLANDS
Community
Wet sedge or Grass-moss
Cryptogam-herb
Polar barrens
% of landscape
3
Herbivore
Caribou
Muskox

FIGURE 9: Assumed High Arctic landscapes with their dominant plant-communities and large herbivores. The first value is the assumed percentage of the total forage that the herbivore obtains from the plant-community (add across). Numbers in brackets indicate the percentage contribution that a given community contributes to the total diet of each herbivore (add down).

replaced by minor areas of dwarf heath on Devon, Ellesmere, and Axel Heiberg islands. The latter are little used by large herbivores. For the purpose of calculating animal densities, the polar deserts have not been included. They will be factored in when animal densities are estimated for the two major regions.

Calculations of plant community areal extent, aboveground phytomass, aboveground net annual plant production, animal foraging percentages of each community, and annual forage consumed per community are given in Table 3. The rate of mean daily food consumption (2.2% of mean body weight) and mean body weight for muskoxen (180 kg) are taken from Hubert (1977). I have assumed a mean body weight of 50 kg and also a 2.2% daily foraging rate for caribou (Table 4). Given the assumptions of forage available for harvest (Table 3), the percentage consumed by each herbivore per habitat (Figure 9), the rate of daily food consumption and mean body weight, it is possible to calculate the maximum herbivore biomass per species for each region (Table 4). For example, muskoxen in the southern islands consume 67% of the low shrub forage (23-34 t) plus 72% of the wet sedge-moss forage (151-227 t) plus 24% of the cushion plant-cryptogam forage (30-101 t), and essentially nothing from the polar desert. This is a total of 204-362 t from this High

Arctic 1,000 km^2 landscape. If muskoxen consume 803% of their live body weight per year (Table 5), a muskox biomass of 25-45 t (204-362 divided by 803% = 25-45) per year is estimated. Comparable calculations for Peary caribou result in an estimated animal biomass of 21-53 t per year. A total plant biomass of 371-785 t/1,000 km^2 is assumed to be harvested by both herbivores per year. Based upon the calculations in Table 6, 420-1,060 caribou and 140-253 muskoxen could be supported on this landscape. These numbers seem very low, but one must remember that only 34% of the landscape contains harvestable vegetation, thus the number of animals supported in those limited lands of sedge-moss meadow (6% of the total landscape) and cushion plant-cryptogam vegetation (28% of the total landscape) in the polar semideserts are actually much higher. The problem rests with the vast areas of polar desert and ice fields (66%).

Based upon the densities of 0.5 caribou and 0.2 muskox/km^2 (Table 6), the southern and eastern islands have a carrying capacity of 254,000 caribou and 14,800 muskoxen. Such numbers have not been reported in modern times, no doubt the product of excessive Inuit hunting, severe winter weather and possibly disease and predation.

Kevan (1974) estimated the muskox population of Banks Island to be 1,200-1,800 animals, and indicated these numbers were higher than previously recorded. Using various data sets from 1961 through 1975, Dickinson and Herman (1979) estimated the muskox population of Banks, Victoria, Prince of Wales, Devon, and Ellesmere islands to be about 8,500 animals. Comparable estimates for Melville, Bathurst, Axel Heiberg and the northwestern islands were about 3,500-4,000 animals.

Similar calculations for the northwestern islands, including Melville Island, result in a harvested plant biomass of 100-185 t/1,000 km^2 that supports a caribou biomass of only 5-10 t and a muskox biomass of 7-13 t (Table 5). Using the average animal weights of 50 kg for caribou and 180 kg for muskoxen and a yearly forage consumption of 803% of mean live body weight, only 100-200 caribou and 39-73 muskox/1,000 km^2 could be supported by these landscapes. Most of the grass-moss meadow vegetation is on Melville Island and thus most of the muskoxen are located there, as animal surveys confirm (Miller 1978). The estimates of 3% wet grass-moss meadow, 55% cryptogam-herb vegetation, and about 42% polar barrens indicate that these landscapes within the western Queen Elizabeth Islands should support approximately 7,500 Peary caribou and 3,750 muskoxen (Table 7). The aerial surveys reported by Miller (1978) estimated 5,200 caribou in 1973 and only 2,700

TABLE 5: ESTIMATED ANNUAL FOOD CONSUMPTION AND HERBIVORE BIOMASS FOR HIGH ARCTIC ECOSYSTEMS UTILIZING THE LANDSCAPE HABITAT OF FIGURE 9.

SPECIES	FOOD CONSUMPTION (% live wt)		FORAGE CONSUMED IN ALL COMMUNITIES (t/yr)	HERBIVORE BIOMASS (t/1000 km^2)
	Daily	Annual		
SOUTHERN AND EASTERN ISLANDS				
Peary caribou	2.2	803	167-424	21-53
Muskoxen	2.2	803	167-424	25-45
NORTHWESTERN ISLANDS				
Peary caribou	2.2	803	40- 77	5-10
Muskoxen	2.2	803	60-107	7-13

TABLE 6: HERBIVORE NUMBERS PER 1,000 KM^2 OF LANDSCAPE BASED UPON HERBIVORE BIOMASS AND MEAN BODY WEIGHT PER SPECIES.

SPECIES	HERBIVORE BIOMASS (t/1,000 km^2)	MEAN BODY wt (t)	NUMBERS 1,000 km^2	NUMBERS km^2
SOUTHERN AND EASTERN ISLANDS				
Peary caribou	21-53	0.05	420-1,060	0.4-1.1
Muskoxen	25-45	0.18	140- 253	0.1-0.3
NORTHWESTERN ISLANDS				
Peary caribou	5-10	0.05	100- 200	0.1-0.2
Muskoxen	7-13	0.18	39- 73	0.04-0.07

in 1974 after severe winter die-off (Miller *et al.* 1975). In 1961 Tener (1963) had estimated24,000 caribou in these western islands. The limiting factors are severe winters with deep-crusted snows and surface-icings and, to a lesser degree, disease and predation. As Miller (1978) mentioned these lands currently support only a fraction of their carrying capacity.

TABLE 7: POTENTIAL LARGE HERBIVORE CARRYING CAPACITY IN THE ARCTIC ISLANDS BASED UPON MAJOR PLANT COMMUNITIES.

REGION AND ANIMAL DENSITY	LAND AREA (km^2)	MAJOR PLANT COMMUNITIES			
		WET MEADOW-CUSHION PLANT COMPLEX	CUSHION PLANT	CRYPTOGAM-HERB	POLAR BARRENS AND ICE
		AREAL EXTENT (km^2)			
Southern and Eastern Islands	1,224,000	74,000	433,000	------	717,000
Northern Islands	123,000	4,000	26,000	45,000	48,000
		POTENTIAL CARRYING-CAPACITY			
Southern and Eastern Islands					
Caribou (0.5/km^2)		37,000	217,000	------	------
Muskox (0.2/km^2)		14,800	-------	------	------
Northwestern Islands					
Caribou (0.1/km^2)		400	2,600	4,500	------
Muskox (0.05/km^2)		200	1,300	2,250	------

There are no recent caribou surveys for all of the southern islands. Kevan (1974) estimated 5,300-8,000 caribou on Banks Island and Fischer and Duncan (1976) estimated 4,300 caribou on Prince of Wales Island. Miller (1978) estimated a total of 10,000 to 15,000 animals in the Canadian Arctic Islands in the mid-1970s. Based upon the above calculations, these lands should be able to support 200,000 to 260,000 animals at a density of 0.5/km^2 in the southern and eastern islands and a density of 0.1/km^2 in the northwestern islands (Table 7). There are indications that barren-ground and Peary caribou numbered between 20,000 and 100,000 animals on Victoria Island early in the century (see Gunn, this volume), and that they migrated annually between the mainland and the island. These herds have been extirpated by Inuit hunters over the years (Manning 1960; Miller 1978).

DEVELOPMENT OF HIGH-ARCTIC ECOSYSTEMS

Following ice retreat 6,000 to 9,000 years ago, coastal areas began to rise as the result of isostatic rebound (Andrews 1970; Barr 1971). With the emergence of new land 10 to 100+ m in elevation, and with successive raised-beach ridges that mark old shorelines, relatively level habitats were provided for plant development. The raised-beach ridges slow the lateral movement of snowmelt waters, enabling surfaces to remain wet most of the summer. These coastal lowlands on the northeastern islands, and valley systems on Ellesmere and Axel Heiberg islands, are the major locations for sedge-moss or grass-moss meadows in the Queen Elizabeth Islands. In the southern islands, valleys and lowlands that are inland as well as coastal are dominated by similar meadows with poorly-drained soils and cushion-plant vegetation on slopes and rolling uplands, habitats that are much drier in summer.

In the northwestern islands, wetlands are rare and only those landscapes with finer-textured soils (usually from old marine sediments) are covered with cryptogam-herb meadow vegetation. These landscapes remain moist all summer due to their cover of cryptogams and soil-texture.

In the rolling uplands on most islands, and the plateau regions of the eastern and central islands, there is almost no vegetation except below huge snowbanks with their snowflush effect. The rest of the landscape has only widely-spaced vascular plants with few cryptogams. These uplands without lichens are probably the result of recent permanent snowcover during the "Little Ice Age", 400 to 600 years ago (Svoboda 1982; Edlund 1985).

The key elements that control vegetation development in the High Arctic are presence of water and adequate nutrients. A continuous supply of water enables mosses to develop, which support colonies of cyanobacteria (bluegreen algae) that fix nitrogen. Symbiotic nitrogen-fixing bacteria occur on the roots of species of *Astragalus*, *Oxytropis* and *Lupinus* in the southern islands and on the mainland. Considerable amounts of nitrogen are fixed as a result (Karagatzides *et al.* 1985). However in the Queen Elizabeth Islands and throughout the entire Arctic Archipelago, nitrogen-fixation by cyanobacteria appears to be the main mechanism. *Dryas integrifolia* occurs in many areas, but it does not fix nitrogen, in contrast with Low-Arctic and high-mountain populations of *Dryas* species.

A few studies now enable us to better assess the role of cyanobacteria in nitrogen-fixation. The methods used in these studies have varied (soil-core incubation time, field vs southern laboratory determination of acetylene-ethylene, and the sophistication of gas-chromatographic instrumentation), but the results give an indication of the magnitude of the process and the mesohabitat control provided by mosses and surface water.

Uplands

On Cornwallis Island a snowflush community of mosses and cyanobacteria had higher nitrogen-fixation rates within the moss-stripes than in the moist, bare soil between the stripes (Table 8). Much higher rates of fixation were reported for isolated temporary pools of water at the base of the hill. Adjacent bare-soil surfaces that lacked any plant-cover had very low rates of fixation (1.2 μg $N_2/m^2/hr$). Comparable values of fixation were reported for the barren plateau on Devon Island (Table 8).

These data clearly show that nitrogen-fixation rates are directly linked to areas that remain moist to wet in summer, and that cyanobacteria are favoured by moss-mats and shallow pools of water. Such habitats are highly limited in these barren lands, so development of a more extensive plant-cover without significant climate change seems unlikely.

Lowlands and Valleys

Lowland coastal areas have developed in much more favourable topographic positions, where water remains on the landscape for longer periods. Consequently, moss-mats have developed in wetter areas with an abundance of sheet and ball *Nostoc commune* and other groups of cyanobacteria. The data (Table 8) show that drier habitats occupied by cushion plant-cryptogam communities have much lower rates of nitrogen-fixation than do the wetter sedge-moss meadows.

Current research indicates that these coastal lowlands have probably developed in two ways. As the land gradually rebounded from the sea and marine algae washed ashore, the decaying plants were invaded by green algae and sequentially by bluegreen algae

TABLE 8: ESTIMATED RATES OF NITROGEN-FIXATION ($\mu gN_2/m^2/hr$) BASED UPON ACETYLENE REDUCTION BY CYANOBACTERIA AND OTHER BACTERIA IN VARIOUS HABITATS IN THE HIGH ARCTIC.

LOCATION AND HABITAT	NITROGEN-FIXATION ($\mu gN_2/m^2/hr$)	AUTHOR
	POLAR BARRENS $\bar{x}$ ± S.D.	
Devon Island - plateau	1.9 ± 0.5	Jordon *et al.* 1978
Cornwallis Island - beach ridge	1.2 ± 1.9	Baumbraugh 1980
Cornwallis Island - small ponds	23.2 + 23.7	Baumbraugh 1980
Cornwallis Island - snowflush with moss	6.4 ± 8.2	Baumbraugh 1980
Cornwallis Island - snowflush bare soil	3.0 ± 3.6	Baumbraugh 1980
	POLAR SEMIDESERT	
Devon Island - beach ridge	7.2 ± 11.3	Stutz 1977
Devon Island - Wolf Hill	1.5 ± 1.1	Stutz 1977
Devon Island - beach ridge	4.8 ± 1.2	Jordon *et al.* 1978
	TUNDRA SEDGE-MEADOW	
Devon Island - mesic meadow	53.4 ± 21.0	Jordan *et al.* 1978
Devon Island - hummock meadow	24.8 ± 16.8	Stutz 1977
Devon Island - Wolf Hill meadow	6.2 ± 3.4	Stutz 1977
Ellesmere Island - Alexandra Fiord meadow	58.8 ± 8.8[1]	Henry and Svoboda 1986
Ellesmere Island - Sverdrup Pass meadow	51.3 ± 3.9[1]	Henry and Svoboda 1986
	COASTAL MEADOW SEQUENCE	
Devon Island - Puccinellia-algal meadow	1,274 ± 538	Chapin and Bliss 1988
Devon Island - Algal hummocks	239 ± 75	Chapin and Bliss 1988
Devon Island - Dupontia-moss meadow	320 ± 94	Chapin and Bliss 1988
Devon Island - Carex-moss meadow	329 ± 92	Chapin and Bliss 1988

[1] S.E.

(cyanobacteria). Where surfaces remain moist from melting snowbanks upslope, the cyanobacteria are able to form organic soil. These organic substrates are invaded by species of *Draba*, *Saxifraga*, *Cerastium*, *Minuartia* and *Salix arctica*. In wetter shoreline basins, graminoids enter early in the sequence. First, *Puccinellia phryganodes* colonizes while the sites are still brackish, then *Dupontia fisheri* and *Alopecurus alpinus* invade as the soils become deeper (10-20 cm) and less influenced by marine waters. In time, with further development of peaty soils that retain water for longer periods in summer, *Carex stans*, *C. membranacea* and *Eriophorum triste* invade. Cyanobacteria are no doubt an important constituent of all of these communities, both in terms of carbon accumulation and especially in nitrogen-fixation. Data (Table 8) demonstrate the abundance of existing nitrogen-fixation in these coastal communities.

The second method of meadow development relates to cutting off large lagoons with adjacent shallow basins. Over time, with further uplift and partial drainage, hypothetically cyanobacteria develop in the shallow shoreline areas along with mosses. As organic matter accumulates with considerable amounts of nitrogen, grasses and sedges become established and eventually develop into the large, wet meadows found today. This same process of shallow water, organic matter build up by algae and mosses, followed by invasion of graminoids, occurred in mountain valleys and basins inland from the coast of Ellesmere and Axel Heiberg islands in the east, as well as on all of the southern islands. Melting snow on slopes above is an essential component.

The deeper organic soils at the base of beach-ridges, in the transition from a beach-ridge crest to a wet meadow below may result from the stranding of marine algae first, followed by colonization of cyanobacteria and probably *Puccinellia phryganodes*. Because these habitats are well-drained a few days after snowmelt, mosses and cyanobacteria are moist for a much shorter time, so organic matter accumulation is greatly reduced in surface soils and rates of nitrogen-fixation are also much less. One might liken these areas to arrested examples of succession that never will develop a thick organic layer with abundant nitrogen from blue-green algal fixation. Consequently, the cushion-plants of *Saxifraga oppositifolia*, *Dryas integrifolia*, *Salix arctica*, and scattered plants of *Papaver*, *Draba*, and *Minuartia* form a stable community that has little chance of developing into a more mesic habitat because of limited water and nitrogen.

On the northwestern islands, the gentle slopes with finer-textured soils are covered with mosses and lichens in which scattered vascular plants occur. Perhaps these plant-communities are limited in their accumulation of organic matter and nitrogen by the relatively thin mat of mosses. This is controlled by the limited amounts of water retained during spring runoff. I further hypothesize that rates of nitrogen-fixation are limited in these landscapes by the reduced mass of cyanobacteria that can be supported. As with the cushion plant-cryptogam communities of the eastern and southern islands, these cryptogam-herb communities have little chance of further development without important climate change and the retention of surface water for longer periods of time.

In summary, throughout the High Arctic, cryptogams (especially mosses) play a critical role in supporting large amounts of cyanobacteria. Where this occurs in coastal lowlands or mountain-valleys, a deeper organic layer forms that can hold water longer, and this permits the cyanobacteria to fix more nitrogen. The deep, wet, organic soils with their higher nitrogen-levels enable the graminoids to form meadows. These wetland oases with their mosaic of better-drained habitats provide the landscape and plant-community diversity so necessary for the support of muskoxen, Peary caribou, lemmings, and the associated birds. The keys are topographic location, abundant water throughout the summer, and the development of soils relatively rich in nitrogen as a result of cyanobacteria. Thus the High Arctic has a mosaic pattern of ecosystems which cannot be easily divided into latitudinal zones.

ACKNOWLEDGEMENTS

Major support for this research over the years has come from: Polar Continental Shelf Project and the Arctic Petroleum Operators Association for logistic aid; the Canadian CCIBP and several federal departments for the original ecosystem study; and recently National Science Foundation grants DEB78-23260, DEB81-07520, and DPP85-20847. Over the years my graduate students have taught me much about the Arctic, and to them I am very grateful.

REFERENCES

Addison, P.A. and L.C. Bliss. 1980. Summer climate, microclimate, and energy budget of a polar semidesert on King Christian Island, N.W.T. Canada. Arctic and Alpine Research 12:161-170.

_____. 1984. Adaptations of *Luzula confusa* to the polar semi-desert environment. Arctic 37:121-132.

Andrews, J.T. 1970. A geographical study of postglacial uplift, with particular reference to Arctic Canada. Institute of British Geography, Special Publication 2.

Banfield, A.W.F. 1974. The mammals of Canada. University of Toronto Press, Toronto. 438 pp.

Barr, W. 1971. Postglacial isostatic movement in northeastern Devon Island: a reappraisal. Arctic 24:249-268.

Baumbraugh, S. 1980. Nitrogen fixation in the High Arctic. (Manuscript).

Bell, K.L. and L.C. Bliss. 1978. Root growth in a polar semidesert environment. Canadian Journal of Botany 56:2470-2490.

_____. 1980. Plant reproduction in a High Arctic environment. Arctic and Alpine Research 12:1-10.

Bird, C.D. 1975. The lichen, bryophyte, and vascular plant flora and vegetation of the Landing Lake area, Prince Patrick Island, Arctic Canada. Canadian Journal of Botany 53:719-744.

Brassard, G.R. and R.E. Longton. 1970. The flora and vegetation of Van Huen Pass, northwestern Ellesmere Island. Canadian Field-Naturalist 84:357-364.

Bliss, L.C. 1977. Introduction. In: Truelove Lowland, Devon Island: A High Arctic Ecosystem. Edited by: L.C. Bliss, University of Alberta Press, Edmonton. p. 1-11.

_____. 1979. Vascular plant vegetation of the Southern Circumpolar Region in relation to antarctic, alpine, and arctic vegetation. Canadian Journal of Botany 57:2167-2178.

_____. 1981. North American and Scandinavian tundras and polar deserts. In: Tundra Ecosystems: A Comparative Analysis. Edited by: L.C. Bliss, O.W. Heal and J.J. Moore. Cambridge University Press, New York. pp. 8-24.

_____. 1986. Arctic ecosystems: their structure, function and herbivore carrying capacity. In: Grazing Research at Northern Latitudes. Edited by: O. Gudmundsson. Plenum Publishing Company, New York. pp. 5-25.

Bliss, L.C. 1988. Arctic tundra and polar desert biome. In: North American Terrestrial Vegetation. Edited by: M.G. Barbour and W.D. Billings. Cambridge University Press, New York. pp. 1-32.

Bliss, L.C. and J.H. Richards. 1982. Present-day arctic vegetation and ecosystems as a predictive tool for the arctic-steppe mammoth biome. In: Paleoecology of Beringia. Edited by: D.M. Hopkins, J.V. Matthews, C.E. Schweger and S.B. Young. Academic Press, New York. pp. 241-257.

Bliss, L.C. and J. Svoboda. 1984. Plant communities and plant production in the western Queen Elizabeth Islands. Holarctic Ecology 7:324-344.

Bliss, L.C., J. Kerik, and W. Peterson. 1977. Primary production of dwarf shrub heath communities, Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 217-224.

Bliss, L.C., J. Svoboda, and D.I. Bliss. 1984. Polar deserts and their plant cover and plant production in the Canadian High Arctic. Holarctic Ecology 7:304-324.

Bryson, R.A. 1966. Airmasses, streamlines and the boreal forest. Geographical Bulletin 8:228-269.

Bryson, R.A., W.N. Irving, and J.A. Larsen. 1965. Radiocarbon and soil evidence of former forest in the southern Canadian tundra. Science 147:46-48.

Chapin, D.M. and L.C. Bliss. 1989. Environmental regulation of nitrogen fixation in High Arctic systems. (Manuscript).

Dickinson, D.M. and T.B. Herman. 1979. Management of some terrestrial mammals in the Northwest Territories for sustained yields. Science Advisory Board of the Northwest Territories, Yellowknife. 71 pp.

Edlund, S.A. 1985. Lichen-free zones as Neoglacial indicators on western Melville Island, District of Franklin. Geological Survey of Canada Paper 85-1A:709-712.

Edlund, S.A. and B.T. Alt. 1989. Regional congruence of vegetation and summer climate patterns in the Queen Elizabeth Islands, Northwest Territories, Canada. Arctic 42:3-23.

Environment Canada. 1982. Canadian climate normals 1951-1980, temperature and precipitation, the northern Yukon and Northwest Territories. Atmospheric Environment Service, Ottawa.

Fischer, C.A. and E. Duncan. 1976. Ecological studies of caribou and muskoxen in the Arctic Archipelago and northern Keewatin. 1975. (Unpublished Report for Polargas).

Freedman, B. and J. Svoboda. 1982. Populations of breeding birds at Alexandra Fjord, Ellesmere Island, Northwest Territories, compared with other arctic localities. Canadian Field-Naturalist 96:56-60.

Freedman, B., J. Svoboda, C. Labine, M. Muc, G. Henry, J. Stewart, and E. Woodley. 1983. Physical and ecological characteristics of Alexandra Fiord, a High Arctic oasis on Ellesmere Island, Canada. In: Permafrost, Fourth International Conference. National Academy Press, Washington, D.C. pp. 301-304.

Fuller, W.A., A.M. Martell, R.F.C. Smith, and S.W. Speller. 1977. Biology and secondary production of *Dicrostonyx groenlandicus* on Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 437-457.

Gray, D.R. 1987. The muskoxen of Polar Bear Pass. Fitzhenry and Whiteside, Markham, Ontario. 191 pp.

Grulke, N.E. and L.C. Bliss. 1983. A note on winter seed rain in the High Arctic. Arctic and Alpine Research 15:261-265.

______. 1988. Comparative life history characteristics of two High Arctic grasses, Northwest Territories. Ecology 69:484-496.

Gunn, A. 1984. Aspects of the management of muskoxen in the Northwest Territories. In: Proceedings of the First International Muskox Symposium. Edited by: D.R. Klein, R.G. White and S. Keller. Biological Papers, University of Alaska, Special Report No. 4:33-40.

Henry, G.H.R. and J. Svoboda. 1986. Dinitrogen fixation (acetylene reduction) in High Arctic sedge meadow communities. Arctic and Alpine Research 18:181-187.

Hills, L.V., J.E. Klovan, and A.R. Sweet. 1974. *Juglans eocinerea* N. Sp., Beaufort Formation (Tertiary), southwestern Banks Island, Arctic Canada. Canadian Journal of Botany 52:65-90.

Hoffman, R.S. and R.D. Taber. 1967. Origin and history of Holarctic tundra ecosystems, with special reference to vertebrate faunas. In: Arctic and Alpine Environments. Edited by: W.H. Osburn and H.E. Wright, Jr. Indiana University Press, Bloomington. pp. 143-170.

Hubert, B.A. 1977. Estimated productivity of muskox on Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 467-491.

Jeffries, R.L. 1977. The vegetation of salt marshes at some coastal sites in arctic North America. Journal of Ecology 65:661-672.

Jordon, D.C., P.J. McNicol, and M.R. Marshall. 1978. Biological nitrogen fixation in the terrestrial environment of a High Arctic ecosystem (Truelove Lowland, Devon Island, N.W.T. Canadian Journal of Microbiology 24:643-649.

Karagatzides, J.D., M.C. Lewis, and H.M. Schulman. 1985. Nitrogen fixation in the high arctic tundra at Sarepa Lake, Northwest Territories. Canadian Journal of Botany 63:974-979.

Kevan, P.G. 1974. Peary caribou and muskoxen on Banks Island. Arctic 27:256-264.

Kuc, M. 1974. Noteworthy vascular plants collected in southwestern Banks Island, N.W.T. Arctic 26:146-150.

Manning, T.H. 1960. The relationship of the Peary caribou and barren-ground caribou. Arctic Institute of North America, Technical Paper No. 4:1-52.

Maxwell, J.B. 1981. Climatic regions of the Arctic Islands. Arctic 34(3):225-240.

Miller, F.L. 1978. Numbers and distribution of Peary caribou on the Arctic Islands of Canada. In: Parameters of Caribou Population Ecology in Alaska. Edited by: D.R. Klein and R.G. White. Biological Papers, University of Alaska, Special Report No. 3:16-19.

Miller, F.L., R.H. Russell, and A. Gunn. 1975. The recent decline of Peary caribou on western Queen Elizabeth Islands of Arctic Canada. Polarforschung 45:17-21.

Muc, M. 1977. Ecology and primary production of the Truelove Lowland sedge-moss meadow communities. In: Truelove Lowland, Devon Island Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 157-184.

Packer, J.G. 1974. Differentiation and dispersal in alpine floras. Arctic and Alpine Research 6:117-128.

Parker, G.R. and R.K. Ross. 1976. Summer habitat use of muskoxen (*Ovibos moschatus*) and Peary caribou (*Rangifer tarandus pearyi*) in the Canadian High Arctic. Polarforschung 46:12-25.

Parker, G.R., D.C. Thomas, E. Broughton, and D.R. Gray. 1975. Crashes in the muskox and Peary caribou populations in 1973-74 on the Parry Islands, Arctic Canada. Canadian Wildlife Service Progress Notes No. 56:1-10.

Pattie. D.L. 1977. Population levels and bioenergetics of arctic birds on Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 413-436.

Polunin, N. 1948. Botany of the Canadian Eastern Arctic, Part III. Vegetation and Ecology. National Museum of Canada, Bulletin 104:1-304.

Polunin, N. 1951. The real Arctic: suggestions for it delimitation, subdivision, and characterization. Journal of Ecology 39:308-315.

Porsild, A.E. 1951. Plant life in the Arctic. Canadian Geographic Journal 42:120-145.

Reznicek, S.A. and J. Svoboda. 1982. Tundra communities along a microenvironmental gradient at Coral Harbour, Southampton Island, N.W.T. Naturaliste Canadien 109:585-595.

Riewe, R.R. and S.W. Speller. 1972. Arctic hare study. Progress Reports, Devon Island Project. Edmonton.

Ritchie, J.C. 1984. Past and present vegetation of the far northwest of Canada. Toronto University Press, Toronto. 251 pp.

Ritchie, J.C., K.A. Hadden, and K. Gajewski. 1987. Modern pollen spectra from lakes in arctic western Canada. Canadian Journal of Botany 65:1605-1613.

Savile, D.B.O. and D.R. Oliver. 1964. Bird and mammal observations at Hazen Camp, northern Ellesmere Island in 1962. Canadian Field-Naturalist 78:1-7.

Sheard, J.W. and D.W. Geale. 1983. Vegetation studies of Polar Bear Pass, Bathurst Island, N.W.T., I. Classification of plant communities. Canadian Journal of Botany 61:1618-1636.

Sohlberg, E. and L.C. Bliss. 1984. Microscale pattern of vascular plant distribution in two High Arctic communities. Canadian Journal of Botany 62:2033-2042.

Stutz, R.C. 1977. Biological nitrogen fixation in High Arctic soils, Truelove Lowlands. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 301-314.

Svoboda, J. 1977. Ecology and primary production of raised beach communities, Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 185-216.

______. 1982. Due to the Little Ice Age climatic impact most of the vegetation cover in the Canadian High Arctic is of recent origin: a hypothesis. Proceedings 33rd Alaskan Science Conference 33:206.

Svoboda, J. and B. Freedman (Editors). 1980. Ecology of a High Arctic lowland oasis. Alexandra Fiord, Ellesmere Island, N.W.T. 1980. Progress Report. (Joint Publication, Departments of Botany, University of Toronto and Dalhousie University).

______. (1989). Ecology of a High Arctic lowland oasis, Alexandra Fiord (78°53'N, 78°55'W), Ellesmere Island, N.W.T., Canada. Department of Botany, University of Toronto.

Tedrow, J.C.F. 1973. Polar soil classification and the periglacial problem. Biuletyn Perzglacjalzny 22:285-294.

______. 1977. Soils of the polar landscapes. Rutgers University Press. New Brunswick, N.J. 638 pp.

Tener, J.S. 1963. Queen Elizabeth Islands game survey 1961. Canadian Wildlife Service, Occasional Paper No. 4:1-50.

Thannheiser, D. 1975. Beobachtung zur Kustenvegetation auf den westlichen kanadischer Arktis-Archipel. Polarforschung 45:1-16.

Thomas, D.C. and J.E. Edmonds. 1984. Competition between caribou and muskoxen, Melville Island, N.W.T. Canada. In: Proceedings of the First International Muskox Symposium. Edited by: D.R. Klein, R.G. White and S. Keller. Biological Papers, University of Alaska, Special Report No. 4:93-100.

Thomas, D.C. and P. Kroeger. 1980. In vitro digestibilities of plant rumen fluids of Peary caribou. Arctic 33:757-767.

Vincent, D. and A. Gunn. 1981. Population increase of muskoxen on Banks Island and implications for competition with Peary caribou. Arctic 34:175-179.

Washburn, A.L. 1956. Classification of patterned ground and review of suggested origins. Geological Society of America, Bulletin 67:823-865.

______. 1980. Geocryology: a survey of periglacial processes and environments. Wiley, New York. 406 pp.

Wilkinson, P.F., C.C. Shank, and D.F. Penner. 1976. Muskox-caribou summer range relations on Banks Island, N.W.T. Journal of Wildlife Management 40:151-162.

Young, S.B. 1971. The vascular flora of St. Lawrence Island with special reference to floristic zonation in the arctic regions. Contributions of the Gray Herbarium, Harvard University 201:11-115.

Yurtsev, B.A. 1972. Phytogeography of northeastern Asia and the problems of Transberingian floristic interrelations. In: Floristics and Paleofloristics of Asia and Eastern North America. Edited by: A. Graham. Elsevier, New York. pp. 19-54.

LICHENS IN THE CANADIAN ARCTIC ISLANDS

John W. Thomson[1]

Abstract: A summary of early exploration of the Canadian Arctic Islands for lichens is followed by an account indicating the accelerated exploration of the present century. The best known islands for lichens include: Axel Heiberg (149 species), Baffin (331 species), Banks (90 species), Bathurst (117 species), Cornwallis (54 species), Devon (163 species), Ellesmere (186 species), Prince Patrick (123 species), Somerset (50 species), Southampton (135 species), and Victoria (40 species). Of the 968 lichens known from the North American Arctic, 456 are so far known to occur on the Canadian Arctic Islands. Further surveys will improve such figures, especially considering that so many of the islands are unexplored for their lichen flora. Much also remains to be investigated on the ecological relationships and adaptations of the lichens in this part of Canada.

Résumé: Un sommaire des premières explorations des îles de l'Arctique canadien est suiv[illegible]stration de la rapidité avec lacquelle elles ont été explorées dans le siècle actuel. Les îles les plus renomées pour leurs esp[illegible] lichens sont: Axel Heiberg (149 espèces), Baffin (331 espèces), Banks (90 espèces), Bathurst (117 espèces), Cornwallis (54 espèces), Devon (163 espèces), Ellesmere (186 espèces), Prince-Patrick (123 espèces), Somerset (50 espèces), Southampton (135 espèces) et Victoria (40 espèces). Des 968 espèces de lichens identifiées dans l'Arctique nord-américain, on en compte actuellement 456 dans les îles de l'Arctique canadien. Des recherches plus poussées devraient améliorer ces chiffres, surtout si l'on considère que la flore des lichens n'a pas encore été étudiée dans un bon nombre de ces îles. Il reste également beaucoup à étudier sur les adaptations et affinités écologiques des lichens dans cette partie du pays.

INTRODUCTION

A polar desert devoid of vegetation and covered by ice may be the popular idea of what the Canadian Arctic Islands are like. In truth, there is a rich lichen flora - even more numerous in species than that of the flowering plants. Long neglected, this group of plants is now becoming the object of intensive research. The opportunities are immense for studies in taxonomy, ecology, and physiology of the arctic lichens, and the progress from a meagre beginning to a richer knowledge is under way.

EARLY EXPLORATION

For a knowledge of the early exploration of the Arctic Islands there is an excellent summary by Lynge (1947) in Polunin's "Botany of the Canadian Eastern Arctic, Part 5".

The earliest expedition to bring back lichens to Europe was that of John Ross in 1818 aboard *Isabella* and *Alexander*. On this voyage only nine lichens were collected from unspecified sites on both the east and west coasts of Baffin Island. The specimens were identified by Robert Brown (1819). On Parry's voyage of 1819-1820, *Hecla* and *Griper* penetrated as far as Winter Harbour on Melville Island. Ten lichens were collected on Melville Peninsula along the way by the surgeon, Mr. Edwards, and by Parry. A few lichens were collected by Dr. Sutherland on the 1850 voyage of Captain William Penny on board *Lady Franklin*. The lichens came from Cornwallis Island and "Banks Land" as well as Greenland but were not clearly identified by Churchill Babington (1852). Penny's ship was one of a squadron involved in the Franklin searches.

---

[1] Department of Botany, University of Wisconsin, Madison, Wisconsin 53706, U.S.A.

Sir Francis M'Clintock on board the *Fox* in Baffin Bay and Prince Regent Inlet in 1857, 1858, and 1859 on the Franklin searches) had Dr. David Walker as surgeon-naturalist who collected plants, including lichens, later identified by J.D. Hooker (1861). The lichens were from Somerset and Devon islands. Although Dr. I.I. Hayes collected along Smith Sound in 1861, the 23 lichens were badly determined according to Theodore Fries (1879), and no localities were given.

The earliest report of consequence was by the Swedish lichenologist Fries (1879). It listed 102 lichens, several new to science, based on material collected by Captain H.W. Feilden on the *Alert* and Mr. H.C. Hart on the *Discovery* - members of Nares Expedition of 1875-1876. The Expedition operated mainly in areas of Ellesmere Island then known as Ellesmere Land, Grinnell Land, and Grant Land, as well as Greenland and the shores of Smith Sound.

On the Howgate Polar Expedition (1877-1878) to Cumberland Sound on the east coast of Baffin Island, the Wisconsin naturalist Ludwig Kumlien collected lichens. Some 53 taxa in 29 species were named by Edward Tuckerman of Harvard University. Curiously, when Milton College, Wisconsin, closed its doors in 1982, its museum collections were disposed of to the University of Wisconsin and some Howgate lichen collections, never sent by Kumlien to Tuckerman, turned up unnamed and still in their original field containers.

Seven specimens were collected by Greely's Expedition of 1882-1883 in northeastern Ellesmere Island. The lichens were determined by E. Lehnert, a minister in Washington, D.C. (Lehnert and Greely 1888). It is a wonder that any lichens at all were collected on this primarily military expedition which involved a dash toward the pole, but which resulted in the death of all but seven expedition members.

Thirty-seven species of lichens were collected on the Norwegian Gjøa Expedition (1903-1907) led by Amundsen. They were mainly from islands west of Gjøa Haven, King William Island, and were determined by Lynge (1921). The Second Norwegian Arctic Expedition under Otto Sverdrup in the *Fram* (1891-1902) worked mainly on Ellesmere Island. A Swedish botanist, H.G. Simmons, on this expedition made a large collection of plants including mosses and lichens. Lichens collected on the expedition were entrusted to Dr. O.V. Darbishire of Oxford University who determined 158 species, and augmented the total in his report with a listing of lichens previously collected from Greenland, Iceland, etc. Unfortunately Lynge, the renowned arctic lichen specialist, considered the determinations to be unreliable. The specimens have never been redetermined completely, since many have been distributed to a variety of herbaria.

J.D. Soper, a naturalist with the Eastern Arctic Patrol of 1923 and several patrols thereafter, collected mosses and lichens on Baffin, Ellesmere and Devon islands. These are in the lichen collections at the National Museum of Natural Sciences (CANL).

In 1931 Nicholas Polunin, well known for publications on arctic flowering plants, collected on Akpatok Island in Ungava. This collection of 35 species was determined by Annie Lorrain Smith and published in 1934.

The Eastern Arctic Patrols of 1934 and 1936 yielded a large number of lichens collected by Nicholas Polunin. They came from Ellesmere, Devon, Philpots, Baffin and Southampton islands, as well as other northern localities. The 1934 collections are in the British Museum (Natural History), the 1936 collections being in the Farlow Herbarium, Harvard University. Lynge's publication on these collections lists 275 species, and is an outstanding summary of lichens to that date in the eastern Canadian Arctic.

Father Arthème Dutilly, Naturaliste des Missions de l'Arctique, collected at several places in northern Canada after 1933. He visited localities on Baffin Island in 1936, (Arctic Bay, Cape Dorset, Clyde River, Pangnirtung, and Lake Harbour), Craig Harbour on Ellesmere Island, Dundas Harbour on Devon Island, and Southampton Island. In 1937, he reached Igloolik Island, and in 1938 Winter Island. His lichens were determined by Lynge (1939). Of the 88 lichens, some 63 were from the Canadian Arctic Islands.

Although the number of specimens collected on these early expeditions were small in the light of modern expectations, the immense difficulties faced on those expeditions should be remembered. The collection of scientific material was mainly by chance. Expeditions focused on exploration and mapping - studies of magnetism, tides, and astronomical observations seemed to be the principal tasks. Perhaps their training in botany as applied to medicinal plants gave early expedition doctors the incentive to collect plants. Lichens were considered too lowly to be of much interest to plant collectors then, despite their dominance in the arctic vegetation. Furthermore, there was the problem of the paucity of storage-space on the small expedition vessels. Perhaps scurvy among crews and officers sapped their energies, which otherwise might have been used for scientific studies and collecting. It is a wonder that any specimens at all reached Europe, considering the problems of man-hauling sledges in many of the early expeditions. Polunin (1940) summarizes the situation plainly and poetically:

> "First thoughts should, perhaps, go to the long line of stoic earlier explorers mentioned above, who ventured forth they knew not where - all too often never to return. Those who were successful in many cases brought back pioneer collections of inestimable value to science, or gained immortality by having their names written on the maps of new regions; those who perished are too often forgotten. With their frail cockle-shells of sailing sloops, hand-drawn sledges, and scurvy-bringing salt foods they one and all helped to pave the way for the modern scientific investigator, whose lot is infinitely more comfortable and less hazardous."

RECENT EXPLORATION

The entry of air transport greatly increased accessibility and scientific activity in the Canadian Arctic Islands. After the Second World War, scientific expeditions could reach quickly and deeply into uncharted areas of the Canadian Arctic. Although collectors were still rarely lichenologists, and their collections were made as a sideline to other official activities, the specimens they gathered have immensely enriched our knowledge of Arctic Islands vegetation.

I attempt here to summarize the wealth of new material that has flowed in to increase our knowledge of the lichen flora of the islands. In some cases I know only the name of the collector and the island(s): in others I can give more detail. Just as with the earlier collectors, most visited the Arctic Islands for other purposes, but the lichens captured their interest and were collected for study by others. Their collections thus became an indispensable source of information on many of the islands. Among the few professional lichenologists who have visited the Canadian Arctic Islands are: Roland Beschel, Charles Bird, I.M. Brodo, Mason E. Hale, J.W. Thomson, and W.A. Weber. The most productive collector of lichens in the Canadian Arctic is George W. Scotter (Canadian Wildlife Service) who has ranged widely across the North in connection with caribou and other wildlife studies, as well as on Parks Canada surveys. His collections have usually been studied by several lichenologists including: Teuvo Ahti (Helsinki), C.D. Bird (Calgary), I.M. Brodo and P.Y. Wong (Ottawa), J.W. Thomson (Wisconsin), and W.A. Weber (Colorado).

The post-Second World War period is probably best covered chronologically. The earliest of these collections was made by the colourful polar expert Alan Innes-Taylor (see Marshall 1984). While Innes-Taylor was a member of a Canadian-United States weather station group during 1947 and 1948 he brought back specimens of 88 species of lichens from Axel Heiberg, Baffin, Bathurst, Cornwallis, Devon, Ellef Ringnes, Ellesmere, and Ward Hunt islands (Thomson 1960). The specimens were the first from some of the remote islands of the archipelago, and are in the lichen herbarium of the National Museum of Natural Sciences (CANL).

In 1969 H.B. Collins collected a few lichens (CANL) on Cornwallis Island. In the same year W.K.W. Baldwin, with the Foxe Basin Expedition on Solomons Temple Islands and islands in James Bay, collected some 81 specimens (CANL) of arctic rock-lichens in connection with spectroscopic examination of rocks.

During 1950 several collectors worked in the islands. A.H. Lawrie collected (CANL) on Ellesmere, Cornwallis, and Devon islands. Stuart D. MacDonald collected some 36 specimens (CANL) on Ellesmere and Prince Patrick islands. R.L. Christie and G. Hattersley-Smith brought back 32 lichens (CANL) from Ellesmere and Ward Hunt islands. The largest collections were made by Mason E. Hale at several localities on Baffin Island. Hale (1954) accompanied the Arctic Institute of North America Expedition to 11 localities on Baffin Island, collecting 257 species (WIS, CANL, US), the largest number reported from the Arctic Islands to that date. J.C. Ritchie collected 57 species (WIS) on Southampton Island in 1954 (Thomson 1956). In 1955, the bryologist R.M.

Schuster collected 108 lichen species (WIS, CANL) near Alert, Ellesmere Island (Schuster *et al.* 1959).

During 1957 John M. Powell collected 38 species (CANL) near Lake Hazen, northern Ellesmere Island, and R. Thorsteinsson brought back lichens (CANL) from Meighen and Mackenzie King islands. About this period, D.B.O. Savile collected (CANL) on Ellef Ringnes Island. During 1959 C.R. Harington collected approximately 65 species (CANL) on Mackenzie King, Cornwallis, and Ellesmere islands - some in collaboration with J.S. Tener.

During the International Botanical Congress (Montreal, 1959), an outstanding field trip by air included the Canadian Arctic Islands (Leonard 1961). Two lichenologists, W.A. Weber (University of Colorado; Figure 1) and J.W. Thomson (University of Wisconsin) participated. Unfortunately, the lichens collected on this trip to Baffin, Cornwallis (Figure 2), Victoria, and Southampton islands, as well as Ungava localities are still being studied. However the work is nearing completion.

In 1960 Alex Dzubin collected (WIS) 14 lichens on Banks Island and 18 on Victoria Island. During 1961 C.R. Harington collected (CANL) on Mackenzie King and Cornwallis islands. In 1964 D.E. McAllister collected six lichens (CANL) on Prince Patrick Island.

During 1964, John Lambert while surveying plant communities on southwestern Banks Island, found a second stand of *Teloschistes arcticus*. This is a lichen which was collected by Parry on Melville Island and described as *Borrera aurantiaca* (Brown 1824, Lambert 1966). It is one of very few endemics in the Canadian Arctic Islands. During the summers of 1967 to 1969, Paul E. Barrett collected 182 species (WIS) on Devon Island (Barrett and Thomson 1975). During 1967, the bryologist Marian Kuc collected 21 species (CANL) from western Axel Heiberg Island at Good Friday Bay. In 1967 also, Royce Longton collected (CANL) at Van Hauen Pass on Ellesmere Island. In 1964 and 1967, the bryologist Guy Brassard collected at Tanquary Fiord, Ellesmere Island and Ward Hunt Island.

The 1970s saw continued activities in the Arctic Islands. In 1972 Stuart MacDonald collected 20 species on Hans Island, and in 1975 he collected 19 specimens on Seymour Island. In 1973, I.M. Brodo and Robert Ireland collected extensively at Polar Bear Pass on Bathurst Island, compiling a list of approximately 175 species of lichens with vouchers

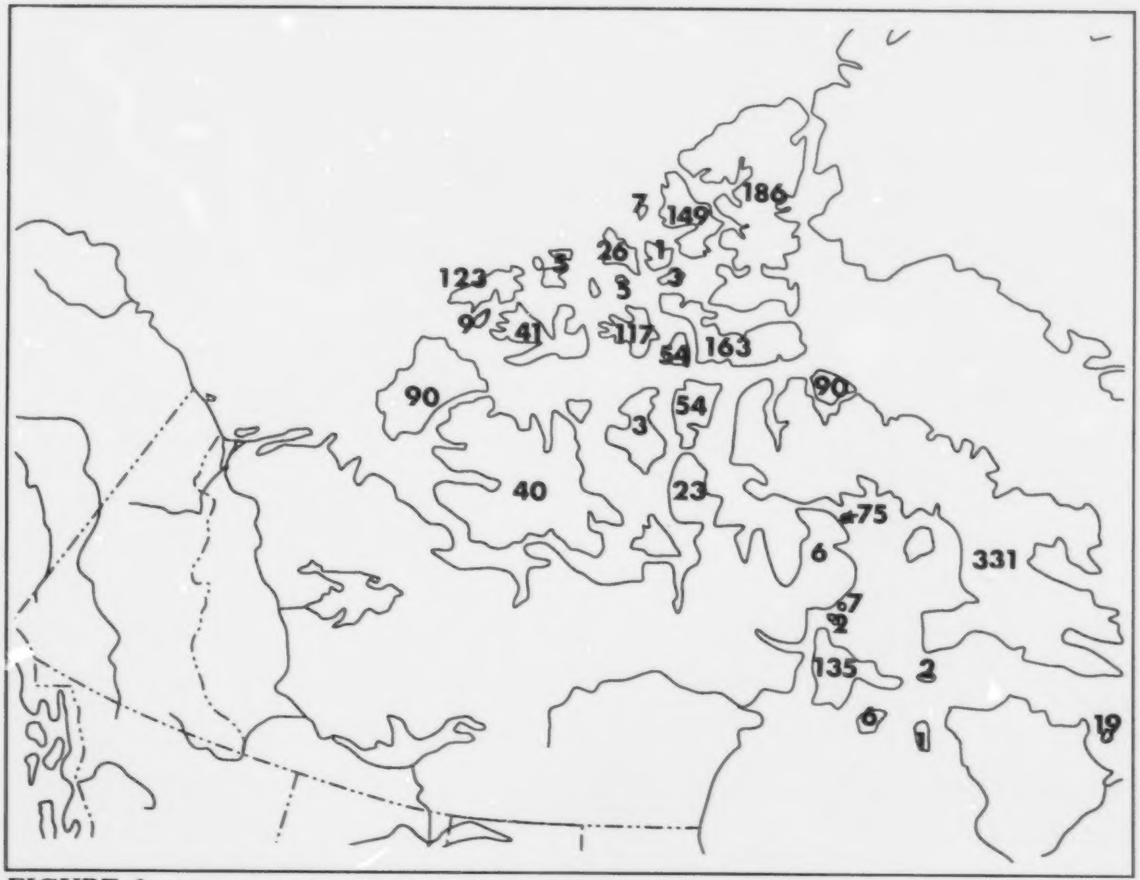

186
7
149
26
1
5
123
3
5
9
41
117
54
163
90
90
3
54
40
23
75
6
331
67
2
135
2
6
1
19

FIGURE 1: The Canadian Arctic Islands showing the number of lichen species known from each.

FIGURE 2: W.A. Weber collecting on a lichen-rich, late-snow rocky slope near Frobisher Bay (Apex), Baffin Island.

in CANL (Brodo, unpublished manuscript). In 1973 C.D. Bird (1975) collected lichens on Prince Patrick Island. He reported 123 species, 103 of them new to the island. In 1974 G. Parker collected 59 specimens at Bailey Point, Melville Island. During 1975 D.W. Wood collected specimens on Victoria Island, while H. Loney Dickson, Norton Miller, and Weston Blake collected at Polar Bear Pass, Bathurst Island. In 1976 Nancy McCartney and Allen P. McCartney studied lichens and their relationship to archaeological sites on Somerset Island, listing 54 species (McCartney 1978). George W. Scotter continued his northern studies, bringing back 179 species from eastern Axel Heiberg Island and the Fosheim Peninsula of Ellesmere Island (Thomson and Scotter 1985).

During 1981, Marjorie L.N. Nams collected 55 specimens on Ellesmere Island. In 1985 Rupert Warren and Ursula Peterson collected independently at Igloolik Island. The specimens are at TRTS and WIS respectively.

LICHEN MAPS FOR THE CANADIAN ARCTIC ISLANDS

Specimens brought back by many of the collectors have not been the subject of special reports. However, as the specimens have been deposited in herbaria such as those of the National Museum of Natural Sciences in Ottawa (CANL), the University of Wisconsin (WIS), or the Farlow Herbarium at Harvard University (FH) (and in the case of the earlier collections in various European herbaria) they became the source of data for many special papers when lichen genera were studied by specialists. I have examined the monographs in search of maps which would incorporate such information on the Arctic Islands (Table 1).

ECOLOGY

Papers specifically describing ecological conditions of lichens in the Arctic Islands are rare. Although listing few lichens, a description of communities on Cornwallis, Southampton, and Victoria islands by Leonard (1961) gives an idea of conditions there.

TABLE 1: LICHEN SPECIES FOR WHICH THERE ARE MAPS IN MONOGRAPHS SHOWING DISTRIBUTION IN THE CANADIAN ARCTIC ISLANDS[1].

Alectoria nigricans, A. ochroleuca, A. sarmentosa (Brodo and Hawksworth 1977)
Allantoparmelia almquistii, A. alpicola (Esslinger 1977)
Asahinea chrysantha (Thomson 1972)
Baeomyces carneus (Thomson 1967)
Buellia epigaea (Thomson 1972)
Bryoria chalybeiformis, B. lanestris, B. nitidula, B. tenuis (Brodo and Hawksworth 1977)
Catapyrenium cinereum, C. lachneum (Thomson 1987)
Cetraria nivalis (Thomson 1972)
Dactylina arctica, D. behringii, D. madreporiformis, D. ramulosa (Thomson and Bird 1978)
Endocarpon tortuosum (Thomson 1972)
Haematomma lapponicum (Thomson 1968)
Lecanora cenisia, L. epibryon (Brodo 1984), L. luteovernalis (Brodo 1984)
Lecidea auriculata (Hertel 1977), *L. hypocrita, L. umbonata* (Hertel 1973)
Massalongia carnosa (Henssen 1963)
Melanelia disjuncta, M. elegantula, M. exasperatula, M. stygia (Esslinger 1977)
Neuropogon sulphureus (Lynge 1940, Thomson 1972)
Pertusaria coriacea, P. dactylina, P. octomela, P. oculata, P. panyrga, P. subobducens (Dibben 1980)
Phaeophyscia sciastra (Thomson 1963)
Physcia caesia, P. dubia (Thomson 1963)
Physconia muscigena (Thomson 1963)
Placopsis gelida (Thomson 1972)
Placynthium aspratile, P. nigrum (Henssen 1963)
Pseudephebe minuscula, P. pubescens (Brodo and Hawksworth 1977)
Ramalina almquistii (Thomson 1972)
Stereocaulon arenarium (Lamb 1972)
Teloschistes arcticus (Thomson 1972)
Umbilicaria cylindrica, U. hyperborea, U. proboscidea, U. vellea (Llano 1950), *U. havaasii* (Thomson 1972)
Vestergrenopsis isidiata (Thomson 1972)

---

[1] It should be noted that for all macrolichens, the maps are updated (see Thomson 1984).

The introduction to Schuster *et al.*, (1959) cites none of the lichens listed in the paper but gives a vivid idea of the polar-desert vegetation of northern Ellesmere Island.

In 1936 Nicholas Polunin made extensive ecological studies of those parts of the islands that he visited. They included parts of Ellesmere, Devon, Cornwallis, Somerset, Baffin, and Southampton islands, as well as Melville Peninsula and other mainland localities, and the islands of Hudson Bay. Polunin's (1948) abundant photographs give an excellent idea of the terrain and plant-cover. In some of his discussions of the communities, lichens are listed or mentioned. Although his publication was delayed until after the Second World War, it is the most comprehensive coverage to that date.

Barrett and Thomson (1975) give information on the coastal lowland of Devon Island, including communities on boulder outcrops, raised-beach crests and foreslopes, and non-sorted circles and nets. Bird (1975) discussed the vegetation on a part of Prince Patrick Island in terms of terricolous species in wet soils, frost-crack and bird-perch areas. Rocky sites were only on silicate rocks, but some were enriched by birds. Some lichens occurred on vegetation, some on old antlers and bone, and some on dung. This useful paper lists 17 site-types and provides photographs of each.

Richardson and Finegan (1977) give recent information on Devon Island, including details of lichen-cover values in the various areas studied, the communities present, the standing crop, as well as much information on lichen physiology and productivity.

LICHENOMETRY

The Canadian Arctic Islands have been the scene of studies using lichen growth-rates in measuring the rates of glacier recession and other phenomena, a science known as lichenometry. The Baffin Island Expedition of 1950 undertook studies of this type at the margin of Barnes Ice Cap. Initial studies by Hale indicated that a recession following a readvance of the southeastern lobe began about 1860 (Ward 1952). From 1961 to 1963 Andrews and Webber (1969), working near the northwestern margin of Barnes Ice Cap, critically evaluated lichenometric studies, and gave dates for the recession of that portion of the ice cap during the last 5,000 years. They also described drainage of a marginal lake about 700 A.D. Two lichens were used in these studies, *Alectoria minuscula* (*Pseudephebe* *minuscula*) and *Rhizocarpon geographicum* (Andrews and Webber 1964, 1969; Andrews 1968; Ives 1962; Løken and Andrews 1966).

During 1960 and 1962 Beschel (1963) worked near Expedition Fiord on Axel Heiberg Island. He cited growth-rates for several lichens present and compared lichen thalli on moraines along the fronts of White and Iceberg glaciers.

SUMMARY

The number of lichen species thus far known from the islands is summarized (Table 2). The best known island in terms of number of species is Baffin with 331. Next is Ellesmere Island with 186, and in sequence: Devon (163), Axel Heiberg (149), Southampton (135), Prince Patrick (123), Bathurst (117) (however 175 species are in Brodo's unpublished study). From there the numbers dwindle, many islands being represented by exceedingly few collections. If an island is not listed, its lichen flora is unknown. Islands best represented are, as would be expected, those that have been visited by professional lichenologists and by outstanding collectors such as Scotter. Figure 3 shows the distribution of the numbers of species known from various islands, and species known from the islands are listed in Table 3 (follows References).

Of the 968 lichens known from the North American Arctic, so far 456 species are known from the Canadian Arctic Islands. Further exploration will improve such figures as 170 species being known from only one island so far, 71 species from two islands, 65 species from three islands, 45 species from four islands, etc. Only one species (*Ochrolechia frigida*) is known from 18 islands, one species (*Physconia muscigena*) from 15 islands, one species (*Thamnolia subuliformis*) from 14 islands, and three species (*Alectoria nigricans, Pachyospora verrucosa*, and *Rhizocarpon geographicum*) from 13 islands.

Although our knowledge of the lichen species that are present on the Arctic Islands is well advanced, it is far from complete, and much more needs to be done. Thomson (1984) merely provides a recent progress report on the status of American Arctic lichens. So many of the islands remain unstudied and the area is so vast that the opportunities are great for future investigators. In the realms of lichen ecology and physiology in the Arctic, an immense amount of work remains. We are in the pioneering stage.

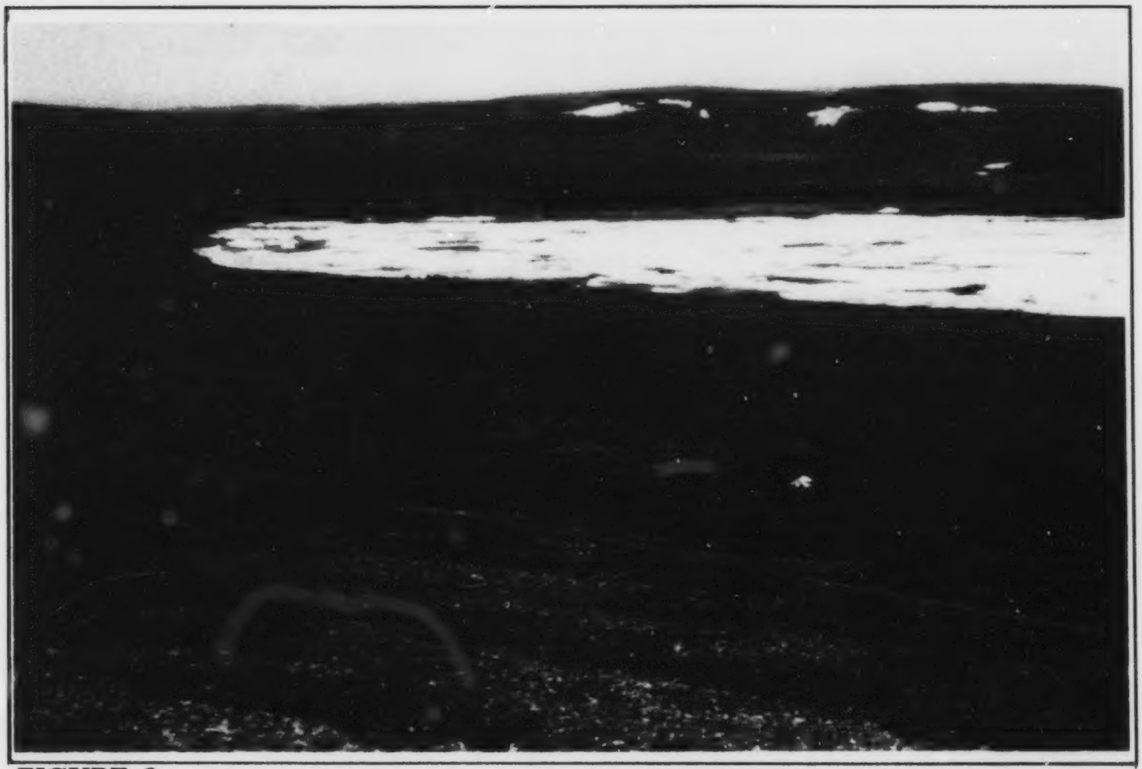


FIGURE 3: High Arctic desert-like area near Resolute, Cornwallis Island. The lichens are mainly confined to the dark areas where drainage during the short spring melt period provides moisture.

ACKNOWLEDGEMENTS

I thank I.M. Brodo for access to his unpublished preliminary paper on Bathurst Island lichens, and Pak Yau Wong for data on some collectors.

TABLE 2: LICHEN SPECIES KNOWN FROM THE CANADIAN ARCTIC ISLANDS[1].

ISLAND	MACROLICHENS	MICROLICHENS	TOTAL
Akpatok	4	15	19
Amund Ringnes	1	0	1
Axel Heiberg	60	89	149
Baffin	143	188	331
Banks	35	55	90
Bathurst	30	87	117
Boothia Peninsula	15	8	23
Borden	3	2	5
Bylot	33	57	90
Coats	4	2	6
Cornwall	1	0	1
Cornwallis	19	35	54
Devon	72	91	163
Eglinton	9	0	9
Ellef Ringnes	15	11	26
Ellesmere	67	119	186
Hans	6	15	21
Igloolik	0	9	9
Lougheed	3	2	5
Mansel	1	0	1
Meighen	7	0	7
Melville	30	11	41
Melville Peninsula	2	4	6
Nottingham	2	0	2
Prince of Wales	2	1	3
Prince Patrick	59	64	123
Seymour	13	7	20
Somerset	29	25	54
Southampton	83	52	135
Vansittart	1	1	2
Victoria	25	15	40
Winter	0	7	7

[1] Includes adjacent areas like Boothia and Melville peninsulas.

REFERENCES

Andrews, J.T. 1968. Late-Pleistocene history of the Isortoq Valley, north central Baffin Island, N.W.T., Canada. Mélanges de Géographie offerts à M. Omer Tulippe 1:118-133.

______. 1964. A lichenometrical study of the northwestern margin of the Barnes Ice Cap: a geomorphological technique. Geographical Bulletin 22:80-104.

Andrews, J.T. and P.J. Webber. 1969. Lichenometry to evaluate changes in glacial mass budgets as illustrated from north-central Baffin Island, N.W.T. Arctic and Alpine Research 1:181-194.

Babington, C. 1852. Notice ... of the lichens collected by Dr. Sutherland during the Arctic voyage of Captain Penny in the '*Lady Franklin*'. Hooker's Journal of Botany 4:276-278.

Barrett, P.E. and J.W. Thomson. 1975. Lichens from a High Arctic coastal lowland, Devon Island, N.W.T. Bryologist 78:160-167.

Beschel, R.E. 1963. Geobotanical studies on Axel Heiberg Island in 1962. In: Axel Heiberg Island Preliminary Report 1961-1962. Edited by: F. Müller. McGill University, Montreal.

Bird, C.D. 1975. The lichen, bryophyte, and vascular plant flora and vegetation of the Landing Lake area, Prince Patrick Island, Arctic Canada. Canadian Journal of Botany 53:719-744.

Brodo, I.M. 1981. *Lecanora luteovernalis*, a new species of the *L. symmicta* complex from the Canadian Arctic. Bryologist 84:521-526.

______. 1984. The North American species of the *Lecanora subfusca* group. Beiheft Nova Hedwigia 79:63-185.

Brodo, I.M. and D.L. Hawksworth. 1977. *Alectoria* and allied genera in North America. Opera Botanica 42:1-164.

Brown, Robert. 1819. "Botanical Appendix" ... In: John Ross. A voyage of discovery ... for the purpose of exploring Baffin's Bay. London. pp. 137-144.

______. 1824. A list of plants collected in Melville Island, by the officers of the expedition; with characters and descriptions of the new species. Supplement to the appendix of Captain Parry's First Voyage. London. pp. 261-310.

Darbishire, O.V. 1909. Lichens collected during the 2nd Norwegian Polar Expedition in 1898-1902. In: Report of the Second Norwegian Arctic Expedition in the "*Fram*", No. 21:1-68.

Dibben, M.J. 1980. The chemosystematics of the lichen genus *Pertusaria* in North America north of Mexico. Milwaukee Public Museum, Publications in Botany and Geology 5:1-162.

Dickie, G. 1869. Notes on mosses, etc., collected by Mr. James Taylor on the shores of Davis Straits. Journal of the Linnean Society, Botany 10:461-467. (Lichens on pp. 465-467).

______. 1871. Notes on a collection of plants from the north-east shore of Lancaster Sound. Journal of the Linnean Society, Botany 11:32-35.

Esslinger, T.L. 1977. A chemosystematic revision of the brown Parmeliae. Journal of the Hattori Botanical Laboratory 42:1-211.

Fries, T.M. 1879. On the lichens collected during the English Polar Expedition of 1875-76. Journal of the Linnean Society, Botany 17:346-370.

Hale, M.E., Jr. 1954. Lichens from Baffin Island. American Midland Naturalist 51:232-264.

Henssen, A. 1963. The North American species of *Massalongia* and generic relationships. Canadian Journal of Botany 41:1331-1346.

______. 1963. The North American species of *Placynthium*. Canadian Journal of Botany 41:1687-1724.

Hertel, H. 1973. Beiträge zur kenntnis der Flechtenfamilie Lecideaceae V. Herzogia 2:479-515.

______. 1975. Über einige gesteinsbewohnende krustenflechten aus der umgebung von Finse (Norwegen, Hordaland). Mitteilen Botanischen München 12:113-152.

______. 1977. *Lecidea* in der Arktis. I. Mitteilen Botanischen München 13:337-352.

Hooker, J.D. 1861. An account of the plants collected by Dr. Walker in Greenland and Arctic America during the expedition of Sir Francis M'Clintock R.N. in the yacht "*Fox*". Journal of the Linnean Society, Botany 5:79-88.

Hooker, W.J. 1825. "Botanical Appendix" ... In: Appendix to Captain Parry's journal of a second voyage for the discovery of a North-west Passage from the Atlantic to the Pacific. Performed in His Majesty's Ships *Fury* and *Hecla* in the years 1821-22-23.

______. 1826. "Botanical Appendix" ... In: W.E. Parry - Journal of a third voyage for the discovery of a North-west Passage from the Atlantic to the Pacific, performed in the years 1824-25, in His Majesty's Ships *Hecla* and *Fury*. Murray, London. pp. 121-131.

Ives, J.D. 1962. Indications of recent extensive glacierization in north-central Baffin Island, N.W.T. Journal of Glaciology 4(32):197-205.

James, T.P. 1863. 'Lichens' ... In: E. Durand, Thos. P. James and Saml. Ashmead. Enumeration of the arctic plants collected by Dr. I.I. Hayes in his exploration of Smith's Sound, between parallels 78th and 82nd, during the months of July, Aug. and beginning of Sept. 1861. Proceedings of the Academy Natural Sciences, Philadelphia 1863: 93-96.

Kuc, M. 1969. Additions to the Arctic moss flora II. Bryophytes and lichens of Good Friday Bay (Axel Heiberg Island, N.W.T., Canada). Revue Bryologique et Lichenologique 36:643-653.

Kunze, G. 1824. Flora der Melville-Insel von R. Brown, nach dem Englischen beiarbeitet und mitgetheilt von Herrn Professor Dr. Kunze. Zweite Beilage zur Flora oder Botanischen Zeitung 1824:65-135.

Lamb, I.M. 1972. *Stereocaulon arenarium* (Sav.) M. Lamb, a hitherto overlooked boreal-arctic lichen. Occasional Papers of the Farlow Herbarium of Cryptogamic Botany No. 2:1-11.

Lambert, J.D.H. 1966. *Teloschistes arcticus* Zahlbr. reaffirmed in the Canadian Arctic. Bryologist 69:358-361.

Lehnert, E. and A.W. Greely. 1886. Mosses and lichens. In: A.W. Greely - Three Years of Arctic Service. Volume 2:392-398.

______. 1888. Mosses and lichens ... In: A.W. Greely - Report on the Proceedings of the United States Expedition to Lady Franklin Bay, Grinnell Land. Washington, Volume 2:18.

Leonard, J. 1961. Relation succinte d'un voyage botanique dans l'arctique Canadien. Les Naturalistes Belges 42:1-28.

Llano, G.A. 1950. A monograph of the lichen family Umbilicariaceae in the western hemisphere. Office of Naval Research, Washington, D.C., Navexos P-831:1-281.

Løken, O.H. and J.T. Andrews. 1966. Glaciology and chronology of fluctuations of the ice margin at the south end of the Barnes Ice Cap, Baffin Island, N.W.T. Geographical Bulletin 8(4):341-359.

Lynge, B. 1921. Lichens from the Gjøa Expedition. Norske videnskaps-akademie, Skrifter I. Matematisk-naturhistoriske, Klasse 15:1-7.

______. 1932. The Godthaab Expedition 1928. The Lichens. Meddelelser om Grønland 82:1-8.

Lynge, B. 1933. On *Dufourea* and *Dactylina*, three Arctic lichens. Skrifter om Svalbard og Ishavet 59:1-62.

______. 1935. Lichens collected during the Danish Fifth Thule Expedition through Arctic Canada. Fifth Thule Expedition Report 2(3):1-39.

______. 1939. A contribution to the lichen flora of Canadian Arctic collection of Father Arthème Dutilly. Farmasoitisk Institut, Oslo. (16 unnumbered pages).

______. 1940. On *Neuropogon sulphureus* (Konig) Elenk., a bipolar lichen. Norsk videnskaps-akadamie, Skrifter Matematisk-Naturhistoriske Klasse 10:1-35.

______. 1947. Lichenes. In: Botany of the Canadian Eastern Arctic. Edited by: N. Polunin. National Museum of Canada, Bulletin 97:298-369.

McCartney, N.M. 1978. Lichens from three archaeological sites, Somerset Island, N.W.T., Canada. Bryologist 81:610-613.

MacDonald, S.D. 1954. Report on biological investigations at Mould Bay, Prince Patrick Island, N.W.T. Annual Report for the fiscal year 1952-53. National Museum of Canada, Bulletin 132:214-238.

Marshall, P.S. 1984. Charles Allan Kenneth Innes-Taylor (1900-1983). Arctic 37(1):84-86.

Polunin, N. 1934. The flora of Akpatok Island, Hudson Strait. Journal of Botany 72:197-204.

______. 1940. Botany of the Canadian Eastern Arctic I. Pteridophyta and Spermatophyta. National Museum of Canada, Bulletin 92:1-408.

______. 1947. Botany of the Canadian Eastern Arctic II. Thallophyta and Bryophyta. National Museum of Canada, Bulletin 97:1-573.

______. 1948. Botany of the Canadian Eastern Arctic III. Vegetation and Ecology. National Museum of Canada, Bulletin 104:1-304.

Powell, J.M. 1967. Some lichens and bryophytes from the Lake Hazen area, Ellesmere Island, N.W.T., Canada. Bryologist 70:250.

Raup, L.M. 1936. Lichens. In: O.E. Jennings - The Exploration of Southampton Island, Hudson Bay. Part 3. Botany. Memoirs of the Carnegie Museum, Pittsburgh 12(3):1-16.

Richardson, D.H.S. and E.J. Finegan. 1977. Studies on the lichens of Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 245-262.

Savile, D.B.O. 1959. The botany of Somerset Island, District of Franklin. Canadian Journal of Botany 37:959-1002.

Schuster, R.M., W.C. Steere, and J.W. Thomson. 1959. The terrestrial cryptogams of northern Ellesmere Island. National Museum of Canada, Bulletin 164:109-122.

Smith, A.L. 1934. Lichenes. In: N. Polunin - The Flora of Akpatok Island, Hudson Strait. Journal of Botany 72:197-204.

Thomson, J.W. 1955. Lichens of Arctic America II. Additions to records of lichen distribution in the Canadian Eastern Arctic. Bryologist 58:246-259.

______. 1956. Lichens of Arctic America III. A collection of lichens from Southampton Island by J.C. Ritchie. Bryologist 59:222-226.

______. 1960. Lichens of Arctic America IV. Lichens collected mainly by A. Innes-Taylor in Greenland and the Canadian Arctic Archipelago. Bryologist 63:181-188.

______. 1963. The lichen genus *Physcia* in North America. Beiheft Nova Hedwigia 7:1-172.

______. 1967. The lichen genus *Baeomyces* in North America north of Mexico. Bryologist 70:258-298.

______. 1968. *Haematomma lapponicum* Räs. in North America. Journal of Japanese Botany 43:305-310.

______. 1972. Distribution patterns of American Arctic lichens. Canadian Journal of Botany 50:1135-1156.

______. 1984. American Arctic Lichens II. The Macrolichens. Columbia University Press, New York. 504 pp.

______. 1987. The lichen genera *Catapyrenium* and *Placidiopsis* in North America. Bryologist 90:27-39.

Thomson, J.W. and C.D. Bird. 1978. The lichen genus *Dactylina* in North America. Canadian Journal of Botany 56:1602-1624.

Thomson, J.W. and G.W. Scotter. 1984. Lichens of Bylot and northern Baffin islands, Northwest Territories, Canada. Bryologist 87:228-232.

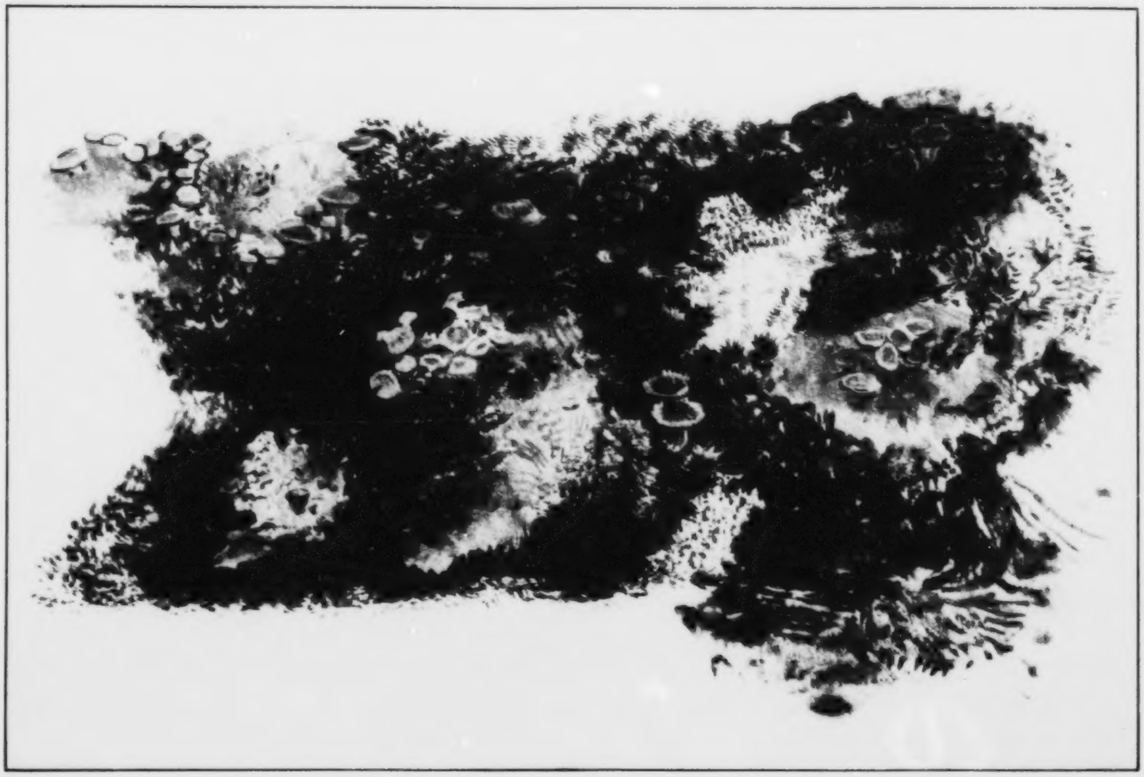
______. 1985. Lichens of eastern Axel Heiberg Island and the Fosheim Peninsula, Ellesmere Island, Northwest Territories. Canadian Field-Naturalist 99:179-187.

Timdal, E. 1986. A revision of *Psora* (Lecideaceae) in North America. Bryologist 89:253-275.

Tuckerman, E. 1879. List of lichens collected in the vicinity of Annanactook Harbour, Cumberland Sound, at about Lat. 67°N, Long. 68°49'W. Bulletin of the United States National Museum 15:167-168.

Ward, W.H. 1952. The glaciological studies of the Baffin Island Expedition 1950. Part 2. The physics of deglaciation of central Baffin Island, with appendix by M.E. Hale. Journal of Glaciology 2:9-23.

Wetherill, H.E. 1895. List of plants obtained on the Peary Auxiliary Expedition of 1894. Bulletin of the Geographical Club (Society) of Philadelphia 1:208-215.



Illustrated by Brenda Carter

TABLE 3: LICHENS OF THE CANADIAN ARCTIC ISLANDS.

Acarospora badiofusca (Nyl.) Th. Fr. **Baffin, Bylot, Banks.**
Acarospora chlorophana (Wahlenb. ex Ach.) Mass. **Axel Heiberg, Baffin, Ellesmere, Prince Patrick, Somerset.**
Acarospora fuscata (Nyl.) Arn. Ach. **Axel Heiberg, Bathurst.**
Acarospora glaucocarpa (Wahlenb. in Ach.) Koerb. **Devon.**
Acarospora molybdina (Wahlenb. in Ach.) Trev. **Baffin, Ellesmere, Victoria.**
Acarospora oxytona (Ach.) Mass. **Baffin.**
Acarospora peliscypha Th. Fr. **Axel Heiberg.**
Acarospora pyrenopsoides Magn. **Ellesmere.**
Acarospora scabrida Hellb. ex Magn. **Axel Heiberg, Ellesmere.**
Acarospora sinopica (Wahlenb. ex Ach.) Koerb. **Baffin.**
Acarospora smaragdula (Wahlenb. ex Ach.) Mass. **Ellef Ringnes.**
Acarospora veronensis Mass **Axel Heiberg, Baffin.**
Agyrophora leiocarpa (DC. in Lam. & DC.) Gyel. **Somerset.**
Agyrophora *lyngei (Schol.)* Llano **Baffin, Devon, Ellesmere, Seymour, Somerset, *Victoria.***
Alectoria nigricans (Ach.) Nyl. **Axel Heiberg, Banks, Bathurst, Boothia Peninsula, Ellef Ringnes, Ellesmere, Meighen, Melville, Prince Patrick, Somerset, Southampton, Victoria.**
Alectoria ochroleuca (Hoffm.) Mass. **Axel Heiberg, Baffin, Banks, Devon, Ellef Ringnes, Ellesmere, Meighen, Melville, Melville Peninsula, Prince Patrick, Seymour.**
Alectoria vexillifera (Nyl.) Stiz. **Baffin, Ellesmere, Southampton.**
Allantoparmelia almquistii (Vainio) Essl. **Baffin.**
Allantoparmelia alpicola (Th. Fr.) Essl. **Baffin, Bathurst, Ellesmere, Southampton.**
Amygdalaria pelobotryon (Wahlenb. in Ach.) Norm. **Baffin.**
Anaptychia setifera Raes. (= *A kaspica*) **Akpatok.**
Arctomia delicatula Th. Fr. **Baffin, Ellesmere.**
Arctoparmelia centrifuga (L.) Hale **Baffin, Boothia Peninsula.**
Arctoparmelia incurva (Pers.) Hale **Baffin, Devon, Southampton.**
Arctoparmelia separata (Th. Fr.) Hale **Axel Heiberg, Baffin, Banks, Devon, Ellesmere, Melville, Melville Peninsula, Prince Patrick, Southampton, Victoria.**
Arthrorhaphis alpina (Schaer.) R. Sant. **Baffin, Prince Patrick.**
Asahinea chrysantha (Tuck.) W. Culb. & C. Culb. **Baffin.**
Aspicilia alboradiata (Magn.) Oxner **Ellesmere.**
Aspicilia alphoplaca (Wahlenb. in Ach.) Poelt & Leuckert **Baffin.**
Aspicilia anseris (Lynge) Thoms. **Axel Heiberg, Baffin, Ellesmere, Igloolik.**
Aspicilia arctica (Lynge) Oxner **Axel Heiberg.**
Aspicilia caesiocinerea (Nyl. ex Malbr.) Arn. **Akpatok.**

- - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Aspicilia candida (Anzi) Hue **Baffin, Banks, Bathurst, Bylot, Cornwallis, Ellesmere.**
Aspicilia cingulata (Zahlbr.) Oxner **Axel Heiberg, Baffin, Ellesmere.**
Aspicilia composita (Lynge) Thoms. **Axel Heiberg, Baffin, Ellesmere.**
Aspicilia contigua (Lynge) Thoms. **Axel Heiberg.**
Aspicilia disserpens (Zahlbr.) Raes. in Huusk. **Baffin, Bylot, Ellesmere, Igloolik, Prince Patrick, Southampton.**
Aspicilia fimbriata (Magn.) Clauz. & Rondon **Baffin.**
Aspicilia lesleyana Darb. **Axel Heiberg, Devon, Ellesmere.**
Aspicilia melanaspis (Ach.) Poelt & Leuckert **Baffin.**
Aspicilia morioides Blomb. ex. Arn. **Baffin, Bylot.**
Aspicilia myrini (Fr. in Myrin) B. Stein **Baffin.**
Aspicilia nathorstii (Lynge) Thoms. **Ellesmere.**
Aspicilia perradiata (Nyl.) Hue **Axel Heiberg, Baffin, Bathurst, Bylot, Ellesmere, Prince Patrick, Southampton.**
Aspicilia pertusa (Lynge) Thoms. **Baffin, Devon.**
Aspicilia plicigera (Zahlbr.) Raes. **Axel Heiberg, Bylot.**
Aspicilia rosulata Koerb. **Baffin, Banks, Bathurst, Bylot, Ellesmere.**
Aspicilia subplicigera (Magn.) Oxner **Cornwallis.**
Aspicilia subradians (Nyl.) Hue **Baffin.**
Aspicilia supertegens Arn. **Baffin, Ellesmere.**
Bacidia bagliettoana (Mass. & DeNot. in Mass.) Jatta **Baffin, Devon, Southampton.**
Bacidia sabuletorum (Schreb.) Lett. (*Mycobilimbia sabuletorum* (Schreb.) Hafellner) **Baffin.**
Bacidia verecundula (Th. Fr.) Magn. **Ellesmere.**
Baeomyces carneus Floerke **Baffin, Ellesmere.**
Baeomyces placophyllus Ach. **Baffin.**
Bellemerea alpina (Sommerf.) Clauz & Roux **Ellesmere.**
Bellemerea cinereorufescens (Ach.) Clauz. & Roux **Banks.**
Brigantiaea fuscolutea (Dicks.) R. Sant. **Baffin, Ellesmere, Igloolik.**
Brodoa oroarctica (Krog) Goward **Baffin, Ellesmere, Southampton.**
Bryocaulon divergens (Ach.) Kaernef. **Axel Heiberg, Baffin, Banks, Devon, Ellesmere, Southampton.**
Bryonora castanea (Hepp) Poelt **Baffin, Devon.**
Bryonora curvescens (Mudd) Poelt **Devon.**
Bryoria chalybeiformis (L.) Brodo & Hawksw. **Baffin, Banks, Devon, Ellesmere, Melville, Prince Patrick, Southampton.**

- - - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Bryoria nitidula (Th. Fr.) Brodo & Hawksw. **Axel Heiberg, Baffin, Bathurst, Devon, Ellesmere, Melville, Prince Patrick, Southampton.**
Buellia aethalea (Ach.) Th. Fr. **Baffin, Ellesmere.**
Buellia alboatra (Hoffm.) Th. Fr. **Ellesmere, Prince Patrick, Victoria.**
Buellia elegans Poelt Ellesmere.
Buellia erubescens Arn. *(B. zahlbruckneri)* **Banks.**
Buellia geophila (Floerke ex Sommerf.) Lynge **Baffin, Bylot, Devon, Ellesmere.**
Buellia leptocline (Flot.) Mass. **Axel Heiberg, Devon.**
Buellia nivalis (Bagl. & Carest) Hertel **Axel Heiberg, Banks, Devon, Prince Patrick.**
Buellia papillata (Sommerf.) Tuck. **Axel Heiberg, Baffin, Banks, Bathurst, Bylot, Cornwallis, Devon, Lougheed, Melville, Prince Patrick, Southampton.**
Buellia pulverulenta (Anzi) Jatta **Banks, Bylot.**
Buellia punctata (Hoffm.) Mass. **Baffin, Bylot, Southampton.**
Buellia spuria (Schaer.) Anzi **Prince Patrick.**
Buellia stigmatea (Ach.) Koerb. **Axel Heiberg.**
Buellia vilis Th. Fr. **Ellesmere**
Caloplaca alcarum Poelt **Axel Heiberg.**
Caloplaca celata Th. Fr. **Banks, Ellesmere.**
Caloplaca cinnamomea (Th. Fr.) Oliv. **Baffin, Ellesmere, Prince Patrick, Southampton.**
Caloplaca cirrochroa (Ach.) Th. Fr. **Baffin, Ellesmere.**
Caloplaca citrina (Hoffm.) Th. Fr. **Bathurst, Ellesmere.**
Caloplaca crenularia (With.) Laund (*C. festiva*) **Axel Heiberg, Baffin, Banks, Bylot, Ellef Ringnes, Southampton.**
Caloplaca *exsecuta (Nyl.)* Dalla Torre & Sarnth. **Bathurst, Melville, Prince Patrick.**
Caloplaca fraudans (Th. Fr.) Oliv. **Baffin.**
Caloplaca friesii Magn. **"South Borden"**[1].
Caloplaca holocarpa (Hoffm.) Wade **Baffin, Banks, Bathurst, Devon, Prince Patrick.**
Caloplaca invadens Lynge **Baffin, Ellesmere.**
Caloplaca jungermanniae (Vahl) Th. Fr. **Axel Heiberg, Baffin, Banks, Bathurst, Devon, Prince Patrick, Southampton.**
Caloplaca saxicola (Hoffm.) Nordin **Baffin, Southampton.**
Caloplaca stillicidiorum (Vahl) Lynge **Axel Heiberg, Baffin, Banks, Boothia Peninsula, Cornwallis, Ellesmere, Prince Patrick, Somerset, Southampton.**
Caloplaca tetraspora (Nyl.) Oliv. **Axel Heiberg, Baffin, Bathurst, Bylot, Devon, Ellesmere, Southampton.**

- - - - - - - - - - - - - -

---

[1] Ed. note: Presumably this refers to Mackenzie King Island, once thought to be the southern part of Borden Island.

TABLE 3: (cont'd)

Caloplaca tiroliensis Zahlbr. **Axel Heiberg, Baffin, Banks, Bathurst, Boothia Peninsula, Bylot, Devon, Ellesmere, Prince Patrick, Somerset, Southampton.**
Caloplaca tominii Savicz **Ellesmere.**
Caloplaca tornoensis Magn. **Baffin.**
Candelariella arctica (Koerb.) R. Sant. **Bylot, Devon.**
Candelariella aurella (Hoffm.) Zahlbr. **Axel Heiberg, Baffin, Banks, Bathurst, Bylot, Cornwallis, Devon, Ellesmere.**
Candelariella dispersa (Raes.) Hakul. **Bathurst, Ellesmere.**
Candelariella placodizans (Nyl.) Magn. **Baffin, Bylot.**
Candelariella terrigena Raes. **Baffin, Banks, Bathurst, Boothia Peninsula, Devon, Ellesmere, Prince Patrick.**
Candelariella vitellina (Hoffm.) Muell. Arg. **Baffin, Bylot.**
Candelariella xanthostigma (Ach.) Lettau **Southampton.**
Carbonea vitellinaria (Nyl.) Hertel **Ellesmere.**
Carbonea vorticosa (Floerke) Hertel **Axel Heiberg, Baffin, Banks, Ellesmere.**
Catapyrenium cinereum (Pers.) Koerb. **Southampton.**
Catapyrenium lachneum (Ach.) R. Sant. **Baffin, Cornwallis.**
Catillaria athallina (Hepp) Hellb. **Cornwallis.**
Catillaria chalybeia (Borrer) Mass. **Baffin.**
Cephalophysis leucospila (Anzi) Kilias & Schneid. **Baffin, Cornwallis, Ellesmere.**
Cetraria andrejevii Oxner **Baffin, Eglinton, Southampton.**
Cetraria commixta (Nyl.) Th. Fr. **Axel Heiberg, Baffin.**
Cetraria cucullata (Bell.) Ach. **Baffin, Banks, Bylot, Cornwallis, Ellesmere, Melville, Prince Patrick, Somerset, Southampton, Victoria.**
Cetraria delisei (Bory ex Schaer.) Nyl. **Akpatok, Baffin, Banks, Bathurst, Bylot, Devon, Ellef Ringnes, Melville, Prince Patrick, Seymour, Southampton, Victoria.**
Cetraria ericetorum Opiz **Baffin, Banks, Boothia Peninsula, Devon, Ellesmere, Seymour, Southampton.**
Cetraria fastigiata (Del. ex Nyl. in Norrl.) Karnef. **Baffin, Borden, Eglinton, Ellef Ringnes, Melville, Prince Patrick, Southampton.**
Cetraria hepatizon (Ach.) Vainio **Baffin, Ellesmere, Prince Patrick, Southampton.**
Cetraria islandica (L.) Ach. **Akpatok, Axel Heiberg, Baffin, Banks, Devon, Ellesmere, Prince Patrick, Southampton.**
Cetraria laevigata Rass. **Axel Heiberg, Banks, Eglinton, Meighen, Melville, Prince Patrick, Somerset.**
Cetraria nigricans Nyl. **Baffin, Ellesmere.**
Cetraria nigricascens (Nyl. in Kihlm.) Elenk. **Axel Heiberg, Baffin, Eglinton, Lougheed, Melville, Prince Patrick, Somerset.**

- - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Certraria nivalis (L.) Ach. **Akpatok, Axel Heiberg, Baffin, Banks, Coats, Devon, Eglinton, Ellesmere, Melville, Prince Patrick, Seymour, Somerset, Southampton.**
Cetraria tilesii Ach. **Baffin, Banks, Boothia Peninsula, Devon, Ellesmere, Melville, Prince of Wales, Prince Patrick, Somerset, Southampton, Victoria.**
Cladina aberrans (Abb.) Hale & W. Culb. **Baffin.**
Cladina mitis (Sandst.) Hustich **Axel Heiberg, Baffin, Banks, Devon.**
Cladina rangiferina (L.) Nyl. **Baffin, Southampton.**
Cladina stellaris (Opiz) Brodo **Baffin.**
Cladonia amaurocraea (Floerke) Schaer. **Axel Heiberg, Baffin, Boothia Peninsula, Bylot, Devon, Prince Patrick, Southampton.**
Cladonia bellidiflora (Ach.) Schaer. **Baffin, Devon, Seymour.**
Cladonia cariosa (Ach.) Spreng. **Baffin.**
Cladonia carneola (Fr.) Fr. **Southampton.**
Cladonia chlorophaea (Floerke ex Sommerf.) Spreng. **Axel Heiberg, Bylot, Coats, Ellesmere.**
Cladonia coccifera (L.) Willd. **Axel Heiberg, Baffin, Coats, Devon, Ellesmere, Southampton.**
Cladonia cornuta (L.) Hoffm. **Baffin, Southampton.**
Cladonia cyanipes (Sommerf.) Nyl. **Baffin.**
Cladonia deformis (L.) Hoffm. **Baffin, Southampton.**
Cladonia ecmocyna Leight. **Axel Heiberg, Banks, Eglinton.**
Cladonia fimbriata (L.) Fr. **Baffin, Southampton.**
Cladonia gracilis (L.) Willd. var. gracilis **Baffin, Devon, Melville, Southampton.**
Cladonia macrophylla (Schaer.) Stenham **Baffin, Southampton.**
Cladonia macrophyllodes Nyl. **Southampton.**
Cladonia pleurota (Floerke) Schaer. **Axel Heiberg, Baffin, Prince Patrick.**
Cladonia pocillum (Ach.) O. Rich. **Axel Heiberg, Baffin, Banks, Bathurst, Boothia Peninsula, Devon, Ellesmere, Prince Patrick, Somerset, Southampton, Victoria.**
Cladonia pyxidata (L.) Hoffm. **Axel Heiberg, Baffin, Banks, Cornwallis, Ellesmere, Prince Patrick, Southampton, Victoria.**
Cladonia stricta (Nyl.) Nyl. **Baffin, Banks, Southampton.**
Cladonia subcervicornis (Vainio) Kernst. **Baffin, Devon, Prince Patrick.**
Cladonia subfurcata (Nyl.) Arn. **Baffin.**
Cladonia uncialis (L.) Weber ex Wigg. **Axel Heiberg, Baffin, Banks, Southampton.**
Coelocaulon aculeatum (Schreb.) Link. **Baffin, Banks, Bathurst, Cornwallis, Devon, Ellesmere, Somerset, Southampton, Victoria.**
Coelocaulon muricatum (Ach.) Laundon **Baffin, Devon.**
Collema ceraniscum Nyl. **Baffin, Bathurst, Devon, Ellesmere, Southampton.**

- - - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Collema fuscovirens (With.) Laund. *(C. tuniforme)* **Ellesmere.**
Collema glebulentum (Nyl. ex Cromb.) Degel. **Baffin.**
Collema tenax (Sw.) Ach. **Baffin, Banks, Cornwallis, Ellesmere, Melville.**
Collema undulatum Laur. ex Flot. **Bathurst, Devon, Ellesmere.**
Coriscium viride (Ach.) Vainio **Baffin.**
Cornicularia divergens Ach. **Axel Heiberg, Baffin, Banks, Devon, Ellesmere, Southampton.**
Dactylina arctica (Richards.) Nyl. **Axel Heiberg, Baffin, Banks, Boothia Peninsula, Eglinton, Melville, Prince Patrick, Somerset, Southampton.**
Dactylina beringica Thoms. & Bird **Baffin, Banks, Devon.**
Dactylina madreporiformis (Ach.) Tuck. **Banks, Bathurst, Bylot, Victoria.**
Dactylina ramulosa (Hook.) Tuck. **Axel Heiberg, Baffin, Banks, Bathurst, Boothia Peninsula, Cornwallis, Devon, Ellesmere, Meighen, Melville, Prince Patrick, Somerset, Southampton.**
Dermatocarpon intestiniforme (Koerb.) Hasse **Devon.**
Dimelaena oreina (Ach.) Norm. **Baffin, Bylot.**
Diploschistes muscorum (Scop.) R.Sant. **Baffin.**
Diploschistes scruposus (Schreb.) Norm. **Baffin, Banks.**
Eiglera flavida (Hepp) Hafellner **Baffin, Bathurst, Ellesmere.**
Endocarpon tortuosum Herre **Baffin.**
Ephebe lanata (L.) Vain. **Baffin.**
Epilichen scabrosus (Ach.) Clem. ex Hafellner **Baffin.**
Evernia perfragilis Llano **Baffin, Banks, Bathurst, Cornwallis, Somerset, Victoria.**
Farnoldia jurana (Schaer.) Hertel **Baffin, Banks, Bathurst.**
Fistulariella almquistii (Vainio) Bowler & Rundel **Boothia Peninsula, Somerset.**
Fulgensia bracteata (Hoffm.) Raes. **Axel Heiberg, Baffin, Banks, Bathurst, Cornwallis, Devon, Melville, Somerset, Southampton.**
Fuscidea mollis (Wahlenb.) V. Wirth & Vezda **Baffin.**
Glypholecia scabra (Pers.) Muell. Arg. **Axel Heiberg.**
Gyalecta foveolaris (Ach.) Schaer. **Banks, Cornwallis, Devon.**
Gyalecta geoica (Wahlenb. ex Ach.) Ach. **Baffin.**
Gyalecta peziza (Mont.) Anzi **Devon, Ellesmere.**
Haematomma lapponicum Raes. **Baffin, Bathurst, Bylot, Devon, Ellesmere, Seymour, Southampton.**
Hymenelia lacustris (Wityh.) Poelt & Vezda **Baffin.**
Hypogymnia austerodes (Nyl.) Raes. **Baffin, Ellesmere, Melville, Southampton.**
Hypogymnia physodes (L.) Nyl. **Baffin, Devon, Southampton.**

- - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Hypogymnia subobscura (Vainio) Poelt **Baffin, Banks, Bathurst, Boothia Peninsula, Ellesmere, Prince Patrick, Seymour, Somerset, Southampton.**

Ionaspis epulotica (Ach.) Blomb. & Forss. **Baffin, Bathurst, Devon, Ellesmere.**

Ionaspis melanocarpa (Kremph.) Arn. **Baffin, Bathurst, Devon, Southampton, Victoria.**

Ionaspis schismatopsis (Nyl.) Hue **Axel Heiberg, Baffin, Banks, Bathurst, Cornwallis.**

Lecania alpivaga Th. Fr. **Baffin, Devon.**

Lecania thallophila Magn. **Bathurst.**

Lecania allophana Nyl. **Southampton.**

Lecanora argopholis (Ach.) Ach. **Baffin, Devon, Prince Patrick.**

Lecanora atrosulphurea (Wahlenb.) Ach. **Axel Heiberg, Baffin, Cornwallis, Devon, Ellef Ringnes, Ellesmere.**

Lecanora beringii Nyl. **Baffin, Bathurst, Bylot, Devon, Prince Patrick.**

Lecanora cenisia Ach. **Axel Heiberg, Baffin, Ellesmere, Prince Patrick, Southampton.**

Lecanora circumborealis Brodo & Vitik. **Baffin.**

Lecanora congesta Lynge **Axel Heiberg.**

Lecanora crenulata Hook. **Axel Heiberg, Bathurst.**

Lecanora dispersa (Pers.) Sommerf. **Axel Heiberg, Baffin, Banks, Bathurst, Cornwallis, Devon, Ellesmere, Prince Patrick.**

Lecanora epibryon (Ach.) Ach. **Axel Heiberg, Baffin, Banks, Bathurst, Bylot, Cornwallis, Devon, Ellesmere, Southampton.**

Lecanora geophila (Th. Fr.) Poelt **Axel Heiberg, Baffin, Prince Patrick.**

Lecanora groenlandica Lynge **Axel Heiberg, Ellesmere.**

Lecanora intricata (Ach.) Ach. **Baffin, Bylot, Devon.**

Lecanora luteovernalis Brodo **Banks, Bathurst, Cornwallis, Devon, Ellesmere, Southampton, Victoria.**

Lecanora marginata Schaer. **Axel Heiberg, Baffin, Banks, Bathurst, Bylot, Cornwallis, Ellef Rignes, Somerset, Southampton.**

Lecanora maxima Lynge **Baffin.**

Lecanora microfusca Lynge **Baffin.**

Lecanora nordenskioeldii Vainio **Baffin, Devon, Somerset.**

Lecanora polytropa (Hoffm.) Rabenh. **Axel Heiberg, Baffin, Banks, Bathurst, Bylot, Devon, Prince Patrick, Southampton.**

Lecanora rupicola (L.) Zahlbr. **Akpatok, Axel Heiberg, Baffin, Banks, Devon, Igloolik, Prince Patrick, Southampton.**

Lecanora torrida Vainio **Baffin, Bathurst, Bylot, Ellesmere.**

Lecanora zosterae (Ach.) Nyl. **Axel Heiberg, Banks, Bathurst, Ellesmere.**

- - - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Lecidea alpestris Sommerf. **Baffin.**
Lecidea atrobrunnea (Ram. in Lam. & DC.) Schaer. **Baffin, Bathurst, Devon.**
Lecidea auriculata Th. Fr. **Axel Heiberg, Baffin, Banks, Bathurst, Ellesmere, Prince Patrick, Southampton.**
Lecidea berengeriana (Mass.) Th. Fr. **Baffin, Southampton.**
Lecidea circumnigrata Magn. in Degel. **Axel Heiberg, Bathurst, Ellesmere, Prince Patrick.**
Lecidea confluens (G. Web.) Ach. **Axel Heiberg, Baffin, Cornwallis, Ellesmere.**
Lecidea cuprea Sommerf. **Axel Heiberg, Baffin, Ellef Ringnes, Melville, Southampton.**
Lecidea diapensiae Th. Fr. **Baffin.**
Lecidea diducens Nyl. **Ellesmere.**
Lecidea ecrustacea (Anzi ex Arn.) Arn. **Baffin.**
Lecidea ementiens Nyl. **Baffin, Ellesmere.**
Lecidea garovaglii Schaer. **Baffin.**
Lecidea hypocrita Mass. **Banks, Bathurst, Cornwallis, Devon, Southampton.**
Lecidea impavida Th. Fr. **Vansittart.**
Lecidea lactea Floerke ex Schaer. (incl. *L. cyanescens* Lynge) **Baffin, Banks, Bathurst.**
Lecidea lapicida (Ach.) Ach. **Axel Heiberg, Baffin, Banks, Bathurst, Devon, Ellesmere, Melville, Prince Patrick, Somerset.**
Lecidea leptoboloides Nyl. **Ellesmere.**
Lecidea leucophaea (Floerke ex Rabenh.) Nyl. **Ellesmere.**
Lecidea limosa Ach. **Axel Heiberg, Devon, Ellesmere, Somerset, Winter.**
Lecidea lithophila (Ach.) Ach. **Akpatok.**
Lecidea lulensis (Hellb.) Stiz. **Axel Heiberg, Baffin, Devon, Ellesmere, Melville, Winter.**
Licidea occidentalis Lynge **Ellesmere.**
Lecidea paupercula Th. Fr. **Ellesmere.**
Lecidea picea Lynge **Axel Heiberg, Baffin, Bylot, Ellesmere.**
Lecidea plana (Lahm. in Koerb.) Nyl. **Ellef Ringnes.**
Lecidea promiscens Nyl. **Southampton.**
Lecidea ramulosa Th. Fr. **Axel Heiberg, Baffin, Banks, Bathurst, Bylot, Coats, Devon, Melville, Seymour, Southampton.**
Lecidea scrobiculata (Th. Fr.) Th. Fr. **Ellesmere.**
Lecidea steineri Hertel **Bathurst, Cornwallis.**
Lecidea sublimosa Nyl. **Ellesmere.**
Lecidea subrhagadiella Lynge. **Baffin.**
Lecidea tenuissima Lynge **Axel Heiberg.**

- - - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Lecidea tessellata (Ach.) Floerke **Axel Heiberg, Baffin, Banks, Bathurst, Cornwallis, Ellesmere.**
Lecidea tornoensis Nyl. **Ellesmere, Prince Patrick.**
Lecidea umbonata (Hepp) Mudd **Axel Heiberg, Baffin, Ellesmere.**
Lecidea vernalis (L.) Ach. **Akpatok, Baffin, Devon, Ellesmere.**
Lecidella bullata Koerb. **Axel Heiberg, Ellesmere.**
Lecidella carpathica Koerb. **Prince Patrick.**
Lecidella euphorea (Floerke) Hertel. **Baffin, Bathurst, Southampton.**
Lecidella inamoena (Muell. Arg.) Hertel **Baffin, Bathurst, Bylot, Devon, Ellesmere, Igloolik, Melville, Victoria.**
Lecidella spitzbergensis (Lynge) Hertel & Leuck. **Axel Heiberg, Bathurst, Ellesmere.**
Lecidella stigmatea (Ach.) Hertel & Leuck. **Axel Heiberg, Baffin, Banks, Bathurst, Cornwallis, Devon, Ellesmere, Prince Patrick, Somerset.**
Lecidella wulfenii (Hepp) Koerb. **Axel Heiberg, Baffin, Bathurst, Boothia Peninsula, Devon, Ellesmere, Seymour, Southampton.**
Lecidoma demissum (Rotstr.) G. Schneid. & Hertel **Baffin.**
Leciophysma finmarkicum Th. Fr. **Axel Heiberg, Baffin, Devon.**
Leptogium arcticum P. Jorg. **Ellesmere.**
Leptogium lichenoides (L.) Zahlbr. **Baffin, Ellesmere, Southampton, Victoria.**
Leptogium minutissimum (Floerke) Fr. **Baffin, Bathurst, Devon.**
Leptogium saturninum (Dickson) Nyl. **Baffin, Prince Patrick.**
Lopadium coralloides (Nyl.) Lynge **Baffin, Southampton.**
Lopadium pezizoideum (Ach.) Koerb. **Baffin, Bathurst, Bylot, Devon, Ellesmere.**
Massalongia carnosa (Dickson) Koerb. **Baffin, Devon, Southampton.**
Melanelia exasperatula (Nyl.) Essl. **Baffin, Ellesmere.**
Melenalia incolorata (Parr.) Essl. *(M. elegantula)* **Baffin, Devon, Ellesmere, Prince Patrick, Southampton.**
Melanelia infumata (Nyl.) Essl. **Axel Heiberg, Baffin, Devon, Ellesmere, Prince Patrick, Southampton.**
Melanelia sorediata (Ach.) Goward & Ahti **Baffin.**
Melanelia stygia (L.) Essl. **Baffin, Devon, Ellesmere, Southampton, Victoria.**
Micarea assimilata (Nyl.) Coppins **Axel Heiberg, Bathurst, Bylot, Cornwallis, Devon, Prince Patrick, Somerset, Southampton.**
Micarea crassipes (Th. Fr.) Coppins *(Helocarpon crassipes* Th. Fr.) **Devon, Ellesmere.**
Micarea incrassata Hedl. **Axel Heiberg, Southampton.**
Micarea lignaria (Ach.) Hedl. **Southampton.**
Mycoblastis affinis (Schaer.) Schauer. **Baffin.**

TABLE 3: (cont'd)

Mycoblastis sanguinarius (L.) Norm. **Baffin.**

Nephroma arcticum (L.) Torss. **Baffin.**

Nephroma expallidum (Nyl.) Nyl. **Baffin, Bylot, Devon.**

Ochrolechia androgyna (Hoffm.) Arn. **Baffin, Bylot, Devon, Southampton.**

Ochrolechia frigida (Swartz) Lynge **Akpatok, Axel Heiberg, Baffin, Banks, Bathurst, Borden, Bylot, Coats, Cornwallis, Devon, Ellesmere, Melville, Melville Peninsula, Prince Patrick, Seymour, Somerset, Southampton, Victoria.**

Ochrolechia grimmiae Lynge **Baffin, Bylot.**

Ochrolechia gyalectina (Nyl.) Zahlbr. **Baffin, Banks, Devon, Ellesmere.**

Ochrolechia inaequatula (Nyl.) Zahlbr. **Baffin, Bathurst, Devon, Seymour.**

Ochrolechia upsaliensis (L.) Mass. **Axel Heiberg, Baffin, Banks, Bathurst, Devon, Southampton.**

Omphalodiscus decussatus (Vill.) Schol. **Axel Heiberg, Baffin, Cornwallis, Ellesmere, Nottingham, Prince Patrick, Somerset, Southampton, Victoria.**

Omphalodiscus krascheninnikovii (Savicz) Schol. **Ellesmere.**

Omphalodiscus virginis (Schaer.) Schol. **Axel Heiberg, Baffin, Banks, Ellef Ringnes, Ellesmere, Somerset, Southampton.**

Orphniospora moriopsis (Mass.) Hawksw. **Baffin, Bylot, Devon, Ellesmere, Somerset.**

Pannaria hookeri (Borrer ex Sm.) Nyl. **Baffin, Devon, Ellef Ringnes.**

Pannaria pezizoides (G. Web.) Trev. **Baffin, Cornwallis, Southampton.**

Pannaria praetermissa Nyl. in Chyd. & Furuhj. **Baffin, Devon.**

Parmelia fraudans Nyl. **Devon, Southampton.**

Parmelia omphalodes (L.) Ach. **Seymour.**

Parmelia saxatilis (L.) Ach. **Baffin, Devon, Igloolik, Southampton.**

Parmelia sulcata Tayl. **Baffin, Devon, Southampton, Victoria.**

Parmeliella tryptophylla (Ach.) Muell. Arg. **Baffin.**

Peltigera aphthosa (L.) Willd. **Axel Heiberg, Baffin, Banks, Bathurst, Boothia Peninsula, Devon, Eglinton, Ellesmere, Melville, Prince Patrick, Somerset, Southampton.**

Peltigera canina (L.) Willd. **Axel Heiberg, Baffin, Banks, Devon, Southampton.**

Peltigera lepidophora (Nyl. ex Vainio) Bitt. **Baffin, Southampton.**

Peltigera leucophlebia (Nyl.) Gyel. **Baffin, Devon, Ellesmere.**

Peltigera malacea (Ach.) Funk. **Axel Heiberg, Baffin, Bathurst, Devon, Lougheed.**

Peltigera polydactyla (Neck.) Hoffm. **Baffin.**

Peltigera rufescens (Weis.) Humb. **Baffin, Bathurst, Cornwallis, Devon, Ellesmere, Mansel, Melville, Southampton.**

Peltigera scabrosa Th. Fr. **Baffin, Bathurst, Devon.**

Peltigera venosa (L.) Hoffm. **Baffin, Banks.**

- - - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Pertusaria alaskensis Erichs. **Devon.**

Pertusaria bryontha (Ach.) Nyl. **Baffin, Bathurst, Devon.**

Pertusaria bryophaga Erichs. **Bathurst.**

Pertusaria coriacea (Th. Fr.) Th. Fr. **Axel Heiberg, Baffin, Bathurst, Bylot, Devon, Ellesmere, Southampton.**

Pertusaria dactylina (Ach.) Nyl. **Axel Heiberg, Baffin, Bathurst, Bylot, Devon, Ellef Ringnes, Ellesmere, Lougheed, Prince Patrick, Seymour, Southampton.**

Pertusaria geminipara (Th. Fr.) Knight **Devon, Prince Patrick.**

Pertusaria glomerata (Ach.) Schaer. **Devon.**

Pertusaria octomela (Norm.) Erichs. **Baffin, Devon.**

Pertusaria oculata (Dicks.) Th. Fr. **Akpatok, Baffin, Bylot, Igloolik.**

Pertusaria panyrga (Ach.) Mass. **Axel Heiberg, Baffin, Bathurst, Cornwallis, Devon, Ellesmere, Melville Peninsula, Southampton.**

Pertusaria pruinifera Erichs. **Devon.**

Pertusaria subobducens Nyl. **Baffin, Bathurst, Bylot, Somerset, Southampton.**

Pertusaria subplicans Nyl. **Ellesmere.**

Pertusaria trochiscea Norman **Baffin, Devon, Prince Patrick.**

Phaeophyscia constipata (Norrl. & Nyl.) Moberg **Axel Heiberg, Baffin, Devon.**

Phaeophyscia endococcinea (Koerb.) Moberg **Baffin, Bathurst.**

Phaeophyscia sciastra (Ach.) Moberg **Baffin, Bathurst, Devon, Ellef Ringnes, Somerset, Southampton.**

Phaeorrhiza nimbosa (Fr.) Mayrh. & Poelt **Axel Heiberg, Baffin, Banks, Bathurst, Boothia Peninsula, Devon, Ellesmere, Somerset, Winter.**

Phaeorrhiza sareptana (Tomin) Mayrh. & Poelt **Baffin.**

Physcia adscendens (Th. Fr.) Oliv. **Southampton.**

Physcia caesia (Hoffm.) Furnrohr. **Baffin, Banks, Bathurst, Cornwallis, Devon, Ellesmere, Somerset, Southampton.**

Physcia dubia (Hoffm.) Lettau **Baffin, Banks, Cornwallis, Devon, Ellesmere, Somerset, Southampton.**

Physconia muscigena (Ach.) Poelt **Axel Heiberg, Baffin, Banks, Boothia Peninsula, Cornwallis, Devon, Ellesmere, Meighen, Melville, Prince Patrick, Seymour, Somerset, Southampton, Victoria.**

Phytoconis viridis (Ach.) Redh. in Kuyper (*Coriscium viride*) **Baffin.**

Placopsis gelida (L.) Linds. **Baffin, Boothia Peninsula, Devon.**

Placynthiella uliginosa (Schrad.) Coppins & P. James **Prince Patrick.**

Placynthium aspratile (Ach.) Henss. **Baffin, Bylot, Devon, Ellesmere, Southampton.**

Placynthium nigrum (Huds.) S. Gray **Bathurst, Cornwallis, Devon, Ellesmere, Victoria.**

Platismatia glauca (L.) W. Culb. & C. Culb. **Baffin.**

- - - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Polyblastia bryophila Lonnr. **Baffin, Bathurst, Devon, Ellesmere, Victoria.**
Polyblastia cruenta (Koerb.) P. James & Swinscow **Ellesmere.**
Polyblastia cupularis Mass. **Akpatopk, Ellesmere.**
Polyblastia gelatinosa (Ach.) Th. Fr. **Baffin, Bathurst, Devon.**
Polyblastia hyperborea Th. Fr. **Baffin, Bathurst, Cornwallis, Devon, Ellesmere, Igloolik, Southampton.**
Polyblastia sendtneri Kremph. **Baffin, Bathurst, Somerset.**
Polyblastia terrestris Th. Fr. **Bathurst.**
Polyblastia theleodes (Somerf.) Th. Fr. **Baffin, Bathurst, Cornwallis, Devon, Ellesmere, Prince Patrick.**
Polychidium muscicola (Sw.) S. Gray **Baffin.**
Polysporina simplex (Davies) Vezda **Axel Heiberg, Baffin, Bylot, Ellesmere, Somerset.**
Porpidia crustulata (Ach.) Hertel & Knoph **Baffin.**
Porpidia flavocaerulescens (Hornem) Hertel & Schwab. **Baffin, Devon.**
Porpidia glaucophaea (Koerb.) Hertel & Knoph **Axel Heiberg, Baffin, Bathurst, Devon.**
Porpidia macrocarpa (DC. in Lam. & DC.) Hertel & Schwab **Baffin, Devon, Prince Patrick.**
Porpidia speirea (Ach.) Krempelh. **Baffin, Banks, Devon, Melville Peninsula.**
Protoblastenia calva (Dickson) Zahlbr. **Akpatok, Baffin, Bathurst, Devon.**
Protoblastenia rupestris (Scop.) Stein. **Baffin, Cornwallis, Ellesmere, Southampton.**
Protoblastenia terricola (Anzi) Lynge **Bathurst, Cornwallis, Ellesmere.**
Protoparmelia badia (Hoffm.) Hafellner **Baffin, Banks, Bathurst, Bylot, Cornwallis, Ellef Ringnes.**
Protothelenella corrosa (Koerb.) Mayrh. & Poelt. **Ellesmere.**
Pseudephebe minuscula (Nyl. ex. Arn.) Brodo & Hawksw. **Axel Heiberg, Baffin, Devon, Ellesmere, Melville, Prince Patrick, Seymour, Southampton.**
Pseudephebe pubescens (L.) Choisy **Axel Heiberg, Baffin, Bylot, Devon, Ellef Ringnes, Ellesmere, Meighen, Melville, Prince Patrick, Southampton.**
Psora decipiens (Hedwig) Hoffm. **Baffin, Banks, Bathurst, Bylot, Ellesmere, Somerset, Southampton.**
Psora rubiformis (Ach.) Hooker **Axel Heiberg, Baffin, Banks, Bylot, Ellesmere.**
Psora tenuifolia Timdal **Ellesmere.**
Psora vallesiaca (Schaer.) Timdal **Bathurst.**
Psoroma hypnorum (Vahl) S. Gray **Baffin, Bylot, Devon, Ellesmere, Southampton.**

- - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Pyrenopsis pulvinata (Schaer.) Th. Fr. (*Euopsis pulvinata*) (Schaer.) Nyl. **Devon.**

Rhizocarpon badioatrum (Floerke ex Spreng.) Th. Fr. **Axel Heiberg, Baffin, Bylot.**

Rhizocarpon chioneum (Norman) Th. Fr. **Baffin, Cornwallis, Devon, Prince of Wales, Victoria.**

Rhizocarpon concentricum (Davies) Beltr. **Baffin.**

Rhizocarpon copelandii (Koerb.) Th. Fr. **Baffin, Bylot, Devon, Ellef Ringnes, Ellesmere.**

Rhizocarpon crystalligenum Lynge **Baffin, Banks, Bylot, Devon.**

Rhizocarpon disporum (Naeg. ex Hepp) Muel. Arg. **Akpatok, Axel Heiberg, Baffin, Banks, Bathurst, Bylot, Devon, Ellesmere, Igloolik, Prince Patrick, Southampton.**

Rhizocarpon distinctum Th. Fr. **Baffin, Ellesmere.**

Rhizocarpon eupetraeum (Nyl.) Arn. **Baffin.**

Rhizocarpon expallescens Th. Fr. **Baffin.**

Rhizocarpon geographicum (L.) DC. **Akpatok, Axel Heiberg, Baffin, Banks, Bathurst, Bylot, Ellef Ringnes, Igloolik, Melville, Prince Patrick, Somerset, Southampton, Victoria.**

Rhizocarpon grande (Floerke ex Flotow) Arn. **Baffin, Ellesmere, Prince Patrick, Winter.**

Rhizocarpon hochstetteri (Koerb.) Vainio **Baffin, Devon, Ellef Ringnes.**

Rhizocarpon inarense (Vainio) Vainio **Baffin, Bathurst.**

Rhizocarpon intermediellum Raes. **Baffin, Bathurst, Cornwallis.**

Rhizocarpon jemtlandicum Lynge **Baffin, Devon, Victoria.**

Rhizocarpon macrosporum Raes. **Prince Patrick.**

Rhizocarpon norvegicum Raes. **Axel Heiberg, Ellesmere.**

Rhizocarpon pusillum Runem. **Axel Heiberg, Bylot, Ellesmere.**

Rhizocarpon rittokense (Hellbom) Th. Fr. **Baffin, Devon.**

Rhizocarpon subtile Runem. **Axel Heiberg, Ellesmere.**

Rhizocarpon superficiale (Schaer.) Vainio **Axel Heiberg, Baffin, Banks, Bathurst, Bylot, Cornwallis, Ellesmere, Prince Patrick, Winter.**

Rhizocarpon umbilicatum (Ram.) Flagey **Bathurst, Ellesmere, Southampton.**

Rhizoplaca chrysoleuca (Sm.) Poelt **Baffin.**

Rhizoplaca melanophthalma (Ram. in Lam. & DC.) Leuck. & Poelt in Leuck. Poelt & Hanel **Akpatok, Axel Heiberg, Baffin, Banks, Bathurst, Ellesmere.**

Rinodina archaea (Ach.) Arn. **Baffin, Ellesmere.**

Rinodina bischoffii (Hepp) Mass. **Baffin, Devon.**

Rinodina calcigena (Th. Fr.) Lynge **Axel Heiberg, Baffin, Bathurst, Devon, Ellesmere.**

Rinodina mniaraea (Ach.) Koerb. **Akpatok, Baffin.**

- - - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Rinodina roscida (Sommerf.) Arn. **Baffin, Banks, Bathurst, Boothia Peninsula, Bylot, Devon, Ellesmere, Somerset, Southampton, Victoria.**
Rinodina turfacea (Wahlenb.) Koerb. **Axel Heiberg, Baffin, Bathurst, Boothia Peninsula, Bylot, Ellesmere, Prince Patrick, Somerset.**
Sagiolechia protuberans (Ach.) Mass. **Bathurst.**
Sagiolechia rhexoblephara (Nyl.) Zahlbr. **Baffin.**
Schaereria tenebrosa (Flotow) Hertel & Poelt **Ellesmere.**
Siphula ceratites (Wahlenb.) Fr. **Baffin, Devon.**
Solorina bispora Nyl. **Axel Heiberg, Baffin, Bathurst, Cornwallis, Ellesmere, Somerset, Southampton, Victoria.**
Solorina crocea (L.) Ach. **Axel Heiberg, Baffin, Bylot, Ellef Ringnes, Melville, Prince Patrick.**
Solorina octospora (Arn.) Arn. **Baffin, Bylot.**
Solorina saccata (L.) Ach. **Axel Heiberg, Baffin, Bylot, Southampton.**
Solorina spongiosa (Ach.) Anzi **Banks, Devon, Ellesmere, Southampton, Victoria.**
Sphaerophorus fragilis (L.) Pers. **Axel Heiberg, Baffin, Bylot, Southampton.**
Sphaerophorus globosus (Huds.) Vainio **Baffin, Bylot, Devon, Ellef Ringnes, Ellesmere, Lougheed, Melville, Prince Patrick, Seymour, Southampton.**
Sporastatia polyspora (Nyl.) Grumm. **Baffin, Bathurst, Ellesmere, Winter.**
Sporastatia testudinea (Ach.) Mass. **Akpatok, Axel Heiberg, Baffin, Banks, Bathurst, Bylot, Cornwallis, Melville, Prince Patrick, Victoria, Winter.**
Staurothele clopima Th. Fr. **Axel Heiberg, Baffin, Bathurst.**
Staurothele fuscocuprea (Nyl.) Zschacke **Akpatok, Bathurst, Southampton.**
Staurothele perradiata Lynge **Banks, Bylot, Ellesmere, Victoria.**
Stereocaulon alpinum Laur. ex. Funck **Axel Heiberg, Banks, Bylot, Devon, Ellef Ringnes, Ellesmere, Prince Patrick, Somerset, Southampton, Victoria.**
Stereocaulon arcticum Lynge **Baffin, Bylot, Ellesmere.**
Stereocaulon arenarium (Savicz) Lamb **Axel Heiberg, Baffin, Bylot.**
Stereocaulon botryosum Ach. **Baffin, Bylot, Devon, Ellef Ringnes, Ellesmere.**
Stereocaulon condensatum Hoffm. **Baffin, Bylot, Ellef Ringnes.**
Stereocaulon coniophyllum Lamb **Baffin, Bylot.**
Stereocaulon glareosum (Savicz) Magn. **Axel Heiberg, Baffin, Bylot, Cornwallis, Melville, Victoria.**
Stereocaulon incrustatum Floerke **Ellef Ringnes.**
Stereocaulon paschale (L.) Hoffm. **Axel Heiberg, Baffin, Cornwall, Ellesmere, "South Borden" (Mackenzie King** - see previous comment), **Southampton.**
Stereocaulon rivulorum Magn. **Amund Ringnes, Axel Heiberg, Baffin, Bylot, Devon, Ellesmere, Prince Patrick, Southampton.**
Stereocaulon symphycheilum Lamb **Bylot.**

- - - - - - - - - - - - - - -

TABLE 3: (cont'd)

Stereocaulon tomentosum Fr. **Baffin.**
Stereocaulon vesuvianum Pers. **Baffin.**
Sticta arctica Degel. **Baffin, Bylot, Southampton.**
Teloschistes arcticus Zahlbr. **Banks, Melville** (and mainland on **Cape Parry**).
Tephromela algaea (Sommerf.) Hertel & Rambold **Baffin.**
Tephromela armeniaca (DC in Lam. & DC.) Hertel **Axel Heiberg, Baffin, Banks, Bylot, Devon, Prince Patrick.**
Tephromela atra (Huds.) Hafellner **Baffin, Devon, Prince Patrick.**
Thamnolia subuliformis (Ehrh.) W. Culb. **Axel Heiberg, Baffin, Banks, Boothia Peninsula, Bylot, Cornwallis, Devon, Ellesmere, Melville, Somerset, "South Borden" (Mackenzie King), Southampton, Victoria.**
Thamnolia vermicularis (Swarz) Ach. ex. Schaer. **Baffin, Banks, Bathurst, Bylot, Ellesmere, Southampton.**
Thelidium minutulum Koerb. **Baffin.**
Thelocarpon epibolum Nyl. **Axel Heiberg.**
Toninia caeruleonigricans (Lightf.) Th. Fr. **Axel Heiberg, Baffin, Cornwallis, Ellesmere, Somerset.**
Toninia lobulata (Sommerf.) Lynge **Baffin, Bathurst, Devon, Ellesmere.**
Toninia squalida (Schleicher ex Ach.) Mass. **Baffin.**
Toninia tristis (Th. Fr.) Th. Fr. **Axel Heiberg.**
Trapelia coarctata (Sm.) Choisy in Werner **Axel Heiberg.**
Trapeliopsis granulosa (Hoffm.) Lumbsch **Prince Patrick.**
Umbilicaria aprina Nyl. **Baffin.**
Umbilicaria arctica (Ach.) Nyl. **Bathurst, Bylot, Devon, Ellesmere, Southampton.**
Umbilicaria cylindrica (L.) Del. ex Duby **Baffin, Boothia Peninsula, Cornwallis, Vansittart.**
Umbilicaria deusta (L.) Baumg. **Baffin, Bylot.**
Umbilicaria havasii Llano **Baffin, Devon, Nottingham, Southampton.**
Umbilicaria hyperborea (Ach.) Hoffm. **Axel Heiberg, Baffin, Bylot, Devon, Ellesmere, Melville, Prince Patrick, Somerset, Southampton, Victoria.**
Umbilicaria proboscidea (L.) Schrader **Axel Heiberg, Baffin, Bathurst, Boothia Peninsula, Bylot, Devon, Ellef Ringnes, Prince Patrick, Southampton.**
Umbilicaria torrefacta (Lightf.) Schrader **Baffin, Bylot, Devon, Southampton.**
Umbilicaria vellea (L.) Ach. **Baffin, Bylot, Devon, Southampton.**
Usnea sphacelata R. Br. **Axel Heiberg, Baffin, Eglinton, Ellesmere, Melville, Prince Patrick, Seymour.**
Verrucaria aethiobola Wahlenb. in Ach. **Bathurst.**
Verrucaria arctica Lynge **Axel Heiberg, Baffin, Banks, Bathurst, Ellesmere, Victoria.**

- - - - - - - - - - - - - - -

TABLE 3: (concl.)

Verrucaria ceuthocarpa Wahlenb. **Baffin.**

Verrucaria devergens Nyl. **Devon, Southampton.**

Verrucaria deversa Vainio **Banks, Bathurst, Cornwallis, Devon, Ellesmere, Somerset.**

Verrucaria margacea (Wahlenb. in Ach.) Wahlenb. **Baffin, Ellesmere.**

Verrucaria maura Wahlenb. in Ach. **Ellesmere.**

Verrucaria muralis Ach. **Bathurst.**

Verrucaria nigrescens Pers. **Baffin, Banks, Bathurst, Devon, Victoria.**

Verrucaria rupestris Schrader **Baffin, Bathurst, Somerset.**

Vestergrenopsis isidiata (Degel.) Dahl **Baffin, Devon.**

Xanthoria candelaria (L.) Th. Fr. **Baffin, Bathurst, Bylot, Cornwallis, Devon, Ellesmere.**

Xanthoria elegans (Link.) Th. Fr. **Axel Heiberg, Baffin, Banks, Bathurst, Devon, Ellesmere, Melville, Prince of Wales, Prince Patrick, Seymour, Somerset, Southampton, Victoria.**

Xanthoria sorediata (Vainio) Poelt. **Baffin, Bylot, Coats, Victoria.**

on nest
July 4
(4 eggs)

Illustrated by Brenda Carter

BIOCLIMATIC ZONES IN THE CANADIAN ARCTIC ARCHIPELAGO

S.A. Edlund[1]

Abstract: Woody plants may be as useful as bioclimatic indicators in the Arctic as trees are in the boreal forest. Northern Canada is divided into seven zones based on common growth-forms of woody plants on mesic soils. Zonal limits coincide remarkably well with mean July isotherms.

All five arctic zones occur in the Canadian Arctic Archipelago. The Low, Erect Shrub Zone roughly coincides with 7° to 10°C mean July isotherms. Many shrub species in this zone reach heights of 25 cm to more than 1 m, with densities ranging from nearly continuous canopies to isolated thickets. Tree-sized deciduous shrubs locally occur in this zone as well. The Dwarfed and Prostrate Shrub Zone roughly coincides with 5° to 7°C mean July isotherms. Woody species capable of low, erect growth are present but dwarfed (less than 25 cm high), and their importance in communities is greatly reduced. Naturally prostrate species such as *Salix arctica* and *Dryas integrifolia* are the dominant shrubs. The Prostrate Shrub Zone roughly coincides with 4-6°C means July isotherms. It, too, is dominated by *Salix* and *Dryas*, but lacks woody species capable of erect growth. The Prostrate Shrub-Herb Transition Zone roughly coincides with 3° to 4°C mean July isotherms. Herbaceous species are dominant, and prostrate shrubs are only sporadically present. The Herbaceous Zone, roughly coinciding with 1-3°C mean July isotherms, is dominated by herbs, and lacks woody plant species.

Résumé: Les plantes ligneuses peuvent être aussi utiles pour servir d'indicateurs bioclimatiques dans l'Arctique que les arbres dans la forêt boréale. Le Nord du Canada est divisé en sept zones selon les normes de croissance courantes des plantes ligneuses en sol mésique. Les limites de ces zones coïncident très bien avec les isothermes moyennes de juillet.

Les zones de l'Arctique, au nombre de cinq, sont toutes présentes dans l'archipel arctique canadien. La zone des sous-arbrisseaux érigés suit à peu près avec les isothermes de juillet de 7° à 10°C. Dans cette zone, un bon nombre d'espèces d'arbustes atteignent des hauteurs allant de 25 cm à plus d'un mètre, avec des densités variant des voûtes de verdure presque continues jusqu'aux bosquets isolés. Des arbustes feuillus de la taille d'un arbre se retrouvent également par endroits dans cette zone. Par ailleurs, la zone des sous-arbrisseaux et des arbrisseaux prostrés correspond approximativement avec les isothermes de juillet de 5° à 7°C. Des espèces ligneuses susceptibles de croissance lente et verticale y sont présentes, mais naines (moins de 25 cm de hauteur), et leur nombre est grandement réduit. Naturellement, les espèces procombantes telles *Salix arctica* et *Dryas integrifolia* sont des arbustes dominants. La zone des arbustes prostrés correspond approximativement aux isothermes de juillet de 4° à 6°C. Les *Salix* et les *Dryas* y prédominent également, mais il y manque des espèces ligneuses capables de croissance érigée. La zone de transition entre les arbustes prostrés et les herbes se situe approximativement aux isothermes de juillet de 3° à 4°C. Les espèces herbacées y sont prédominantes, tandis que les arbustes prostrés y sont dispersés. La zone des herbacées, qui coïncide à peu près avec les isothermes de juillet de 1° à 3°C, comprend surtout des herbes et pas d'espèces de plantes ligneuses.

INTRODUCTION

From the air much of the Arctic appears nearly devoid of vegetation because of the absence of trees and the shortness of arctic plants. This "barrens" image is reinforced in some areas of the Arctic, where soils derived from extremely alkaline or acidic bedrock do not permit plant growth. Most soils, however, support plant communities which in turn support major herbivore populations. Woody plants, including low, erect shrubs, to dwarfed, prostrate or matted shrubs, are major component of mesic plant communities over most of the Arctic.

---

[1] Terrain Sciences Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8
Geological Survey of Canada Contribution Number 10488

Two basic factors influence modern vascular-plant diversity and distribution: geology and climate. Many plant species and associations have preferences for, or intolerances to, chemical, textural and moisture variations of soils. Some species prefer weakly to moderately alkaline soils, while others do not tolerate such conditions. Similarly, some species have specific moisture requirements. For example, aquatic sedges require poorly-drained to saturated soil throughout most of the growing season. Other species can not tolerate such an abundance of moisture. Therefore, within a given area, each type of parent material has a suite of plant communities, each favouring a particular moisture regime. In the Arctic, where soils in summer are still underlain by permafrost and a few centimetres difference in elevation makes a great difference in the moisture availability, a mosaic - pattern of plant assemblages is characteristic (Polunin 1960; Bliss 1975, this volume).

Regional climate plays a large role in controlling the composition of arctic vegetation. Climate affects the diversity, density, productivity, and growth-forms of the vascular plants for any given type of substrate by controlling the temperature, length of the thaw-season, variations in precipitation, and intensity and duration of cloud-cover.

Summer warmth has the greatest influence on vegetation diversity (Young 1971; Rannie 1985). This control is best expressed as summations of total warmth such as Melting Degree-Days or Growing Degree-Days. Such data, however, are generally available only for the sparse network of northern weather stations (Atmospheric Environment Service 1982). The most readily available and widespread measure of summer warmth is the mean temperature for July, the warmest month (Figure 1).

In the Canadian Arctic, mean July isotherms grade northward from roughly 10°C near treeline to 1°C along the northwestern rim of the Queen Elizabeth Islands. This decline is not a simple, linear, latitudinal progression but a complex pattern reflecting the interaction between solar radiation received, characteristics of the dominant air-mass, topography, and amount of open water surrounding the islands during the summer (Edlund 1983A, 1986A).

On a global scale, the Arctic generally has been treated as a unit, even though this circumpolar ecosystem spans up to 31° of latitude. There are, however, several broad subdivisions of the North American Arctic ecosystem. Polunin (1951, 1960; Energy, Mines and Resources Canada 1973) divided the Arctic into three regions, Low, Mid, and High Arctic, based primarily on the abundance of continuous ground-cover and species diversity.

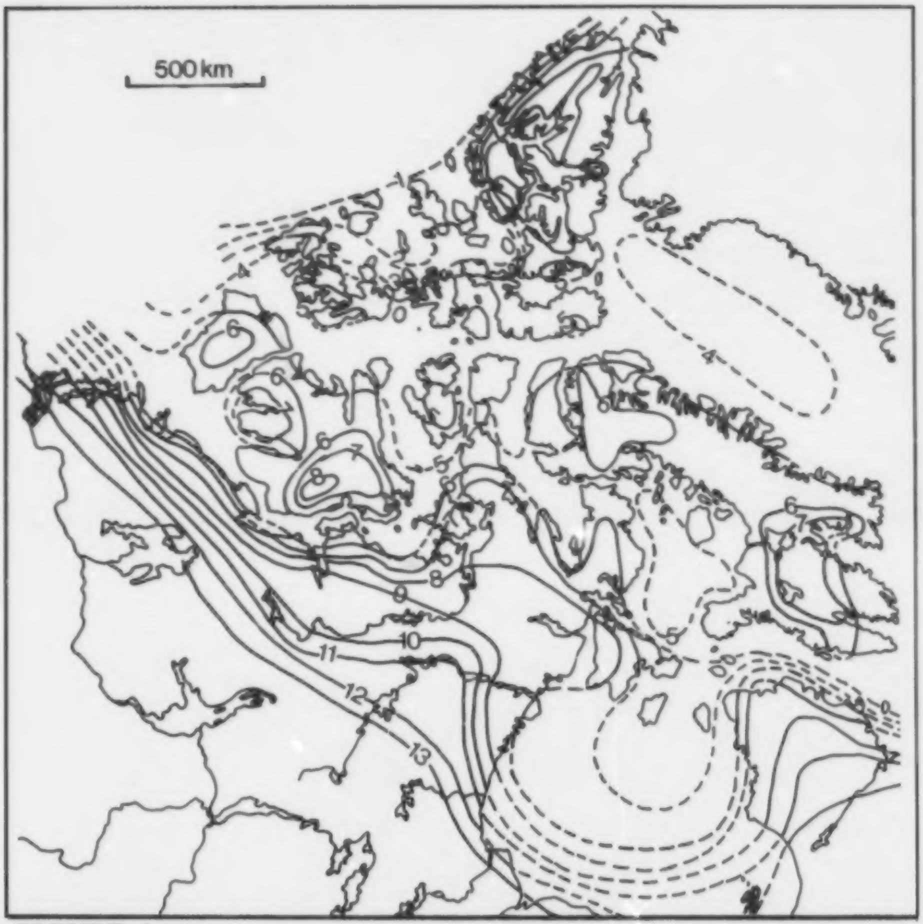


FIGURE 1: Mean July Temperatures in northern Canada, derived from northern weather stations (Atmospheric Environment Service 1982), community records, and selected non-standard weather data collected by Polar Continental Shelf Project (after Edlund 1986A).

Young (1971) proposed a circumpolar classification of arctic vegetation based on the diversity of vascular plants. He created four zones north of treeline that reflect the progressive impoverishment of vegetation poleward. He suggested that the primary ecological factor involved is the amount of available summer warmth.

Bliss (1977, this volume) divides the Canadian Arctic into two major regions on the basis of density and continuity of vegetation-cover: Low Arctic, encompassing the continental region north of treeline and the southeastern corner of Baffin Island; and High Arctic, which includes all islands of the Canadian Arctic Archipelago, as well as Boothia and Melville peninsulas and Wager Plateau in northern Keewatin. He further subdivided the High Arctic into three zones (Babb and Bliss 1974): Polar Desert, Polar Semidesert, and a Complex, including Polar Desert, Polar Semidesert, and sedge-meadows. All three High Arctic zones occur throughout the Arctic Islands, although the Complex is more prevalent in the more southerly sector of the islands.

Detailed regional maps of plant associations for some areas of Arctic Canada (Edlund 1980, 1982A,B,C, 1983B,C,D, 1987B) revealed several broad vegetation patterns that could not be explained satisfactorily by previous proposed subdivisions. Comparisons with climatic patterns, particularly summer-temperature patterns, revealed great similarities between major vegetation changes and degree of severity of the summer climate (Edlund 1983A, 1986A). Because of the names Low, Mid, and High Arctic have been applied to different areas by different authors, I have avoided their use in the units that are described here, even though in a few regions some boundaries are similar. The new zones, instead, are named for the dominant vascular plant growth - form on mesic terrain. Nomenclature for vascular plants follows that of Porsild and Cody (1980).

BIOCLIMATIC ZONES IN ARCTIC CANADA

Seven major bioclimatic zones are delineated in northern Canada (Figure 2). Two of these encompass the transition from treed terrain to tundra. The other five are zones of the "true" or treeless Arctic. These zones are characterized by plant habitat and number of vascular-plant species and the roughly coincident mean July isotherms. They should not be interpreted directly as physiologically-significant temperatures, but rather as relative indicators of regional warmth.

Regional diversity within the seven bioclimatic zones was calculated by overlaying the Canada-wide zones on individual species range maps (Porsild 1964; Porsild and Cody 1980). Recent range extensions are also included. Total flora of a zone was compiled, irrespective of the chemistry, or drainage characteristics of soils. As Young (1971) and Rannie (1985) found, diversity of vascular plants decreases dramatically through the zones with decreasing summer temperatures. The diversity of both woody species and of species associated with wetlands and pond environments drops sharply, particularly where mean July temperatures drop below 7°C, whereas total diversity declines more gradually (Figure 3). Perennial

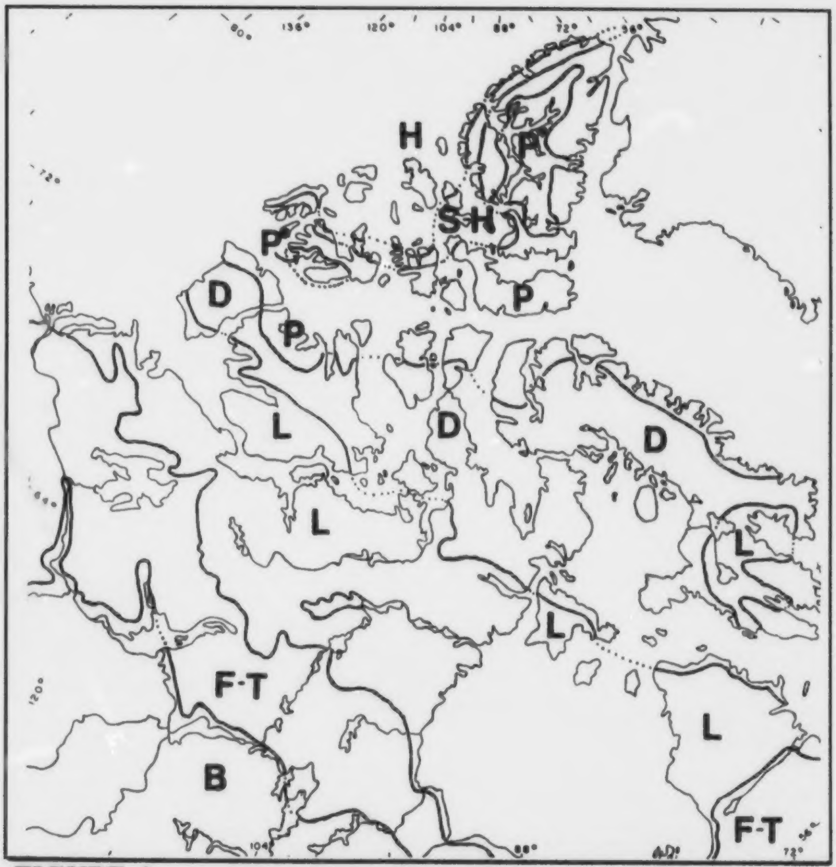

80°
136°
120°
104°
88°
72°
56°
72°
64°
120°
104°
88°
72°
H
P*
S-H
P*
D
P
P
L
D
D
L
L
L
F-T
L
B
F-T

FIGURE 2: Bioclimatic zones in northern Canada. Key: B = Northern Boreal Forest; F-T = Boreal Forest-Tundra Transition Zone; L = Low, Erect Shrub Zone; D = Dwarfed and Prostrate Shrub Zone; P = Prostrate Shrub Zone; P* = Enriched Prostrate Shrub Zone; S-H = Prostrate Shrub-Herb Transition Zone; H = Herb Zone.

herbaceous species make up the largest number of taxa in all zones. Annuals are rare in the Arctic, and biennials are few and generally restricted to the warmest zones.

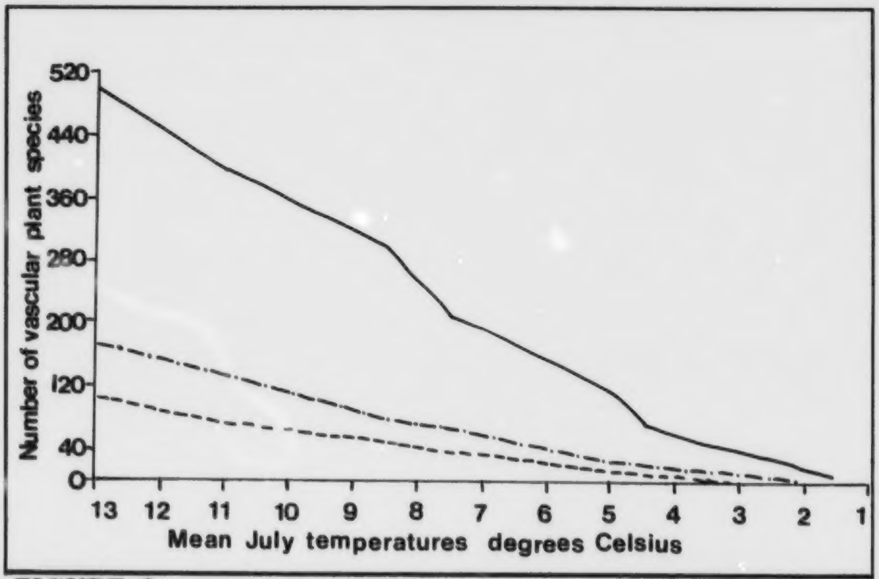


FIGURE 3: **Diversity of vascular plants in the bioclimatic zones. Key: Solid line = Total number of vascular plant species; dashes and dots = number of wetland aquatic and emergent species; dashed line = number of woody species.**

The seven major bioclimatic zones represent major shifts in vegetation patterns with increasingly severe summers. Although the zones were named to reflect changes in growth-forms and significance of woody species on mesic terrain, they also represent changes in density and diversity of herbaceous species in wetlands.

Northern Boreal Forest

The northern limit of the boreal forest, which coincides with the southernmost extent of the arctic biome, is one of the best known phytogeographic and bioclimatic boundaries. This limit roughly coincides with the mean position of the Arctic front in summer (Bryson 1966) and also with the 13°C mean July isotherm (Hare 1970). Compared to other northern zones, diversity is greatest within the Northern Boreal Forest Zone: over 500 vascular-plant species occur near the northern limit of the boreal forest, including more than 100 woody species and many temperate genera (Table 1) such as cherry (*Prunus*), currant (*Ribes*), mountain ash (*Sorbus*), dogwood (*Cornus*), silverberry (*Elaeagnus*), blueberry and bilberry (*Vaccinium*), and willow (*Salix*). The erect, single-trunked tree is the dominant vascular plant growth-form in this zone.

Near the northern forest-limit this continuous coniferous forest, confined to the northern mainland of Canada, is dominated by spruce (*Picea*). Other conifers such as larch (*Larix*),

TABLE 1: INDICATOR SHRUBS IN THE SEVEN NORTHERN BIOCLIMATIC ZONES AND CORRESPONDING MEAN JULY ISOTHERMS.

VEGETATION ZONE	MEAN JULY ISOTHERM °C	MAJOR WOODY SPECIES	INDICATOR SHRUBS AND TREES REACHING THEIR NORTHERN LIMITS WITHIN THE ZONE
NORTHERN BOREAL FOREST ZONE	13+	*Picea mariana* (Mill.) B.S.P. *Picea glauca* (Moench) Voss *Larix laricina* (DuRoi) Koch *Pinus banksiana* Lamb. *Betula papyrifera* Marsh *Populus balsamifera* L.	*Cornus canadensis* L. *Cornus stolonifera* Michx. *Elaeagnus commutata* Bernh. *Juniperus horizontalis* Moench *Prunus pennsylvanica* L. *Ribes glandulosum* Grauer *Ribes lacustre* (Pers.) Poir. *Salix barrattiana* Hook. *Salix interior* Rowlee *Salix lasiandra* Benth. *Salix padophylla* Rydb. *Salix scouleriana* Barratt *Salix serrissima* (Bailey) Fern. *Sorbus scopulina* Greene *Vaccinium caespitosum* Michx. *Vaccinium myrtilloides* Michx.
FOREST-TUNDRA TRANSITION ZONE	10-13	*Picea mariana* (Mill.) B.S.P. *Picea glauca* (Moench) Voss *Alnus crispa* (Ait.) Pursh *Betula glandulosa* Michx. *Cassiope tetragona* (L.) D.Don erect *Rhododendron lapponicum* (L.) Wahlenb. *Salix alaxensis* (Anderss.) Cov. *Salix bebbiana* Sarg. *Salix lanata* L. ssp. *calcicola* (Fern. & Weath.) Hult. *Salix lanata* L. ssp. *richardsonii* (Hook.) Skvortsov *Salix planifolia* Pursh	*Amelanchier alnifolia* Nutt. *Arctostaphylos uva-ursi* (L.) Spreng. *Betula occidentalis* Hook. *Betula papyrifera* Marsh *Betula pumila* L. *Chamaedaphne calyculata* (L.) Moench *Juniperus communis* L. *Kalmia polifolia* Wang. *Larix laricina* (DuRoi) Koch *Ledum groenlandicum* Oeder *Linnaea borealis* L.[1] *Myrica gale* L. *Oxycoccus microcarpus* Turcz. *Populus balsamifera* L. *Populus tremuloides* Michx. *Potentilla fruticosa* L.[1] *Ribes hudsonianum* Richards. *Ribes triste* Pall. *Rosa acicularis* Lindl. *Rubus acaulis* Michx. *Rubus strigosus* Michx. *Salix arbusculoides* Anderss.[1]

- - - - - - - - - - - - - - -

TABLE 1: (cont'd)

VEGETATION ZONE	MEAN JULY ISOTHERM °C	MAJOR WOODY SPECIES	INDICATOR SHRUBS AND TREES REACHING THEIR NORTHERN LIMITS WITHIN THE ZONE
			Salix brachycarpa Nutt. *Salix interior* Rowlee *Salix myrtillifolia* Anderss. *Salix pedicellaris* Pursh *Salix pyrifolia* Anderss. *Shepherdia canadensis* (L.) Nutt. *Vibernum edule* (Michx.) Raf.
LOW, ERECT SHRUB ZONE	7-10	*Cassiope tetragona* (L.) D.Don *Dryas integrifolia* M. Vahl *Ledum decumbens* (Ait.) Lodd. *Salix arctica* Pall. *Salix lanata* ssp. *richardsonii* (Hook.) Skvortsov	krummholz of *Picea mariana* (Mill.) B.S.P. *Alnus crispa* (Ait.) Pursh *Andromeda polifolia* L. *Betula glandulosa* Michx. *Loiseleuria procumbens* (L.) Desv. *Phyllodoce coerulea* (L.) Bab. *Rubus chamaemorus* L. *Salix alaxensis* (Anderss.) Cov.[1] *Salix fullertonensis* Schneid. *Salix glauca* L. *Salix niphoclada* Rydb.[1] *Salix planifolia* Pursh *Salix pulchra* Cham.
DWARFED AND PROSTRATE SHRUB TUNDRA	5-7	*Cassiope tetragona* (L.) D.Don *Dryas integrifolia* M. Vahl *Salix arctica* Pall.	*Arctostaphylos alpina* (L.) Spreng. *Arctostaphylos rubra* (Rehd. & Wils.) Fern. *Diapensia lapponica* L. *Empetrum nigrum* L.[1] *Ledum decumbens* (Ait.) Lodd *Rhododendron lapponicum* (L.) Wahlenb.[1] *Salix arctophila* Cockerell *Salix cordifolia* Pursh *Salix herbacea* L.[1] *Salix lanata* ssp. *richardsonii* (Hook.) Skvortsov *Salix polaris* Wahlenb.[1] *Salix reticulata* L.[1] *Vaccinium uliginosum* L.[1] *Vaccinium vitis-idaea* L.

- - - - - - - - - - - - - - -

TABLE 1: (cont'd)

VEGETATION ZONE	MEAN JULY ISOTHERM °C	MAJOR WOODY SPECIES	INDICATOR SHRUBS AND TREES REACHING THEIR NORTHERN LIMITS WITHIN THE ZONE
PROSTRATE SHRUB ZONE	4-6	*Dryas integrifolia* M. Vahl *Salix arctica* Pall.	*Cassiope tetragona* (L.) D.Don
PROSTRATE SHRUB-HERB TRANSITION ZONE	3-4	none	*Dryas integrifolia* M. Vahl *Salix arctica* Pall.
HERBACEOUS ZONE	1-3	none	none

[1] Species found under exceptionally favourable local conditions in the zone directly northward.

fir (*Abies*) and pine (*Pinus*) are also present (Rowe 1972; Ritchie 1984; Richard 1987). Tall deciduous shrubs and small trees of birch (*Betula*), alder (*Alnus*), aspen (*Populus*), and willow (*Salix*) occur in this zone too (Gill 1973; Gilbert and Payette 1982; Ritchie 1984), often as successional species in opening or disturbed terrain such as river margins. The coniferous shrub common juniper (*Juniperus communis*) also occurs this zone.

Wetlands, dominated by sedges, contain over 170 wetland (growing in poorly-drained soils), emergent (growing with lower stems partially submerged), and aquatic (vegetative growth totally submerged) species. A number of woody species and herbs are present on mounds of peat, which afford slightly better-drained conditions.

Forest-Tundra Transition Zone

In regions where mean July temperatures fall below 13°C, the continuous forest is absent. The tree growth-form persists, however, and woody plants continue to dominate all but the wettest terrain. Between 13° and 12°C, trees commonly occur in an open formation; between 12° and 10°C, trees are generally restricted to favoured locations such as sunny slopes and sheltered, well-watered valley bottoms. Low, erect shrubs, 25-100 cm high, occur in many parts of this zone both as individual clumps and as dense thickets on moderately to imperfectly-drained materials, although lichens are the common ground-cover on some areas of the Canadian Shield. Prostrate (low and sprawling) shrubs are more common on thin, well-drained soils and on more exposed sites. Multi-branched, small tree-sized deciduous shrubs such as *Salix* and *Alnus* occur on floodplains and disturbed terrain. The total vascular plant diversity is greater than 400 species, including at least 75 woody species.

Wetlands contain about 130 wetland, aquatic, and emergent species, (still rich by northern standards), as well as a variety of sedges, shrubs and herbs. Sedges are still the dominant vascular plants.

Treeline, the northern limit of the coniferous tree growth-form and the northern limit of the Forest-Tundra Transition Zone, occurs on the continental mainland. Treeline does not occur on any of the Arctic Islands, however it comes close to the northern continental margin near the head of Horton and Coppermine rivers and the Mackenzie Delta. It coincides roughly with the 10°C mean July isotherm (Nordenskjöld and Mecking 1928; Hare 1970). Many other, more temperate woody species include small, deciduous trees such as poplar (*Populus*), birch (*Betula*), *Alnus*, a few *Salix* species and serviceberry (*Amelanchier*), and shrubs such as northern rose (*Rosa acicularis*), shrubby cinquefoil (*Potentilla fruticosa*), bog laurel (*Kalmia polifolia*), sweet gale (*Myrica gale*), spirea (*Spirea beauverdiana*), soapberry (*Sherpherdia canadensis*), twin flower (*Linnaea borealis*), common Labrador tea (*Ledum groenlandicum*), cranberry (*Oxycoccus microcarpus*) and common bearberry (*Arctostaphylos uva-ursi*) (Table 1).

Low, Erect Shrub Zone

The best vegetated region of the "true" (treeless) Arctic occurs immediately north of treeline including: the northernmost mainland, southern Banks, Victoria, and Baffin islands, and the islands in Hudson and James bays. Mean July temperatures within this region range between 10° and 7°C. Over 300 vascular-plant species occur in this zone, of which more than 50 are woody. This is the arctic zone with the greatest vascular-plant density and diversity (Figure 3).

Conifers are generally absent, except near treeline, where the low shrub *Juniperus communis* and *Picea*, which locally occurs in a severely dwarfed, or "krummholz" growth-form (Figure 4), both may be found. Woody plants, particularly low, erect shrubs (25 cm to 1 m high or more), such as dwarf birch (*Betula glandulosa*) and *Salix*, as well as

FIGURE 4: Krummholz of Picea mariana, in the Coppermine River area, near treeline. Note also the size of dwarf birch (Betula glandulosa) in the foreground.

FIGURE 5: Low, erect Salix lanata var. richardsonii on Victoria Island. The low thickets are 25-50 cm high.

ericaceous species such as arctic white heather (*Cassiope tetragona*) and northern Labrador tea (*Ledum decumbens*) are dominant. In the warmest sectors, the low shrub-thicket canopy (0.5-1.0 m high) can be nearly continuous on sheltered, well-watered slopes. In the cooler sectors, the dense low-shrub thickets (25-50 cm high) are restricted to more sheltered locations (Figure 5). Exposed terrain and thin soils are dominated by prostrate shrubs, such as arctic avens (*Dryas integrifolia*), and arctic willow (*Salix arctica*), or low ericaceous species (Table 1).

Tree-sized (2-7 m high) felt leaf willows (*Salix alaxensis*) locally occur in this zone, generally on floodplains near the edges of deep channels and in sheltered locations (Maycock and Matthews 1966; Edlund and Egginton 1984). Away from stream margins, this same willow species commonly adopts the more usual low, erect growth-form.

Wetlands contain 75 wetland, aquatic, and emergent species. Sedges still dominate and low, erect shrubs and a variety of herbs often occur on slightly better-drained terrain within the wetlands. The most continuous coverage of tussock-cotton grass tundra (mainly *Eriophorum vaginatum*), primarily found on extensive fine-grained sediments of coastal lowlands, is also found in this zone.

The Low, Erect Shrub Zone marks the northern limit of many common arctic-shrub species such as dwarf birches (*Betula glandulosa* and *B. nana*), green alder (*Alnus crispa*), andromeda (*Andromeda polifolia*), alpine azalea (*Loiseleuria procumbens*), mountain heather (*Phyllodoce coerulea*), and cloudberry (*Rubus chamaemorus*).

Dwarfed and Prostrate Shrub Zone

In regions with mean July temperatures between 7° and 5°C, the low, erect shrub growth-form is absent, although species capable of erect growth, such as *Salix alaxensis*, *Salix lanata* var. *richardsonii*, and *S. niphoclada* still occur. The growth-form of these species is stunted (less than 25 cm high; Figure 6). These dwarfed species, generally restricted to sheltered, well-watered sites, are only a small part of the plant communities.

Mesic soils in the zone are usually dominated by genetically-dwarfed shrubs. One such species is the prostrate arctic willow (*Salix arctica*), whose branches sprawl along the ground. Its lateral extent can total a metre or more (Figure 7)! Another common species is the matted shrub *Dryas integrifolia*, which occurs abundantly on neutral to moderately alkaline soils. These two species are also present in more southerly zones, but are restricted to

FIGURE 6: Salix lanata var. richardsonii in its dwarfed "krummholz" form on Victoria Island. The trowel shows that this low thicket is less than 12 cm high.

FIGURE 7: Artic willow (Salix arctica), the most common prostrate shrub in the Canadian Artic Islands. Its branches can extend to a diameter of more than a metre.

thinner soils and more exposed terrain. Vascular plant species diversity in this zone ranges from 150 to 300 species, including 17 woody species.

Wetland communities, dominated by sedges, contain 35 wetland, aquatic and emergent species. Both dwarfed and prostrate shrub species are present on slightly better-drained hummocks. *Eriophorum* tussock-tundra may also occur, although its coverage is not as dense or extensive as it is in the Low, Erect Shrub Zone.

This zone occurs extensively in the southern tier of Arctic Islands, on the mainland on Boothia and Melville peninsulas, and on a strip along the northern coast of Ungava Peninsula. Its northern limit is south of Parry Channel. It generally marks the northern extent of shrub species capable of erect growth, including northern Labrador tea (*Ledum decumbens*), Lapland rosebay (*Rhododendron lapponicum*), several *Salix* species, a number of naturally prostrate ericaceous species and *Empetrum nigrum* (Table 1).

Prostrate Shrub Zone

In regions where mean July temperatures range between 6° and 4°C, the plant assemblages are generally similar to those in the Dwarfed and Prostrate Shrub-Tundra Zone, but shrubs capable of erect growth are absent. The woody species *Salix arctica* and *Dryas integrifolia* still dominate mesic terrain. On the whole, the flora of this zone is less diverse. Most obviously absent are Leguminosae (particularly *Oxytropis* and *Astragalus*), arctic fireweed (*Epilobium latifolium*), and many Compositae - particularly those with erect flowering stems such as *Senecio congestus*, *Petasites frigidus*, and *Arnica alpina*, as well as the more compact *Antennaria compacta*, *Chrysanthemum integrifolium*, *Crepis nana*, and *Erigeron* species. *Cassiope tetragona*, the hardiest heath species, is restricted to neutral to acid soils in the warmer sectors with mean July temperatures at least 5°C. Less obvious are decreases in numbers of grass and sedge species. Vascular-plant diversity ranges from 75 to 150 species, including 12 woody species.

Wetlands are still dominated by sedges, but their diversity is reduced to three common species, *Carex aquatilis* var. *stans*, *Eriophorum triste* and *E. scheuchzeri*. *Eriophorum* tussock-tundra does not occur in this zone, although the species itself may occur locally. Only 24 wetland, aquatic and emergent species occur in this zone. Grasses, particularly *Dupontia fisheri* and *Alopecurus alpinus*, are common associates in these wetlands, and may locally become dominant, particularly on bare mineral soils.

There are two widely separated areas within this zone where floral assemblages are exceptionally rich: western Melville Island and west-central Ellesmere Island (Edlund 1986B). These "enriched zones" resemble the Dwarfed and Prostrate Shrub Zone, except for the absence of species capable of erect shrub growth (e.g. *Salix alaxensis*, *S. lanata* and *S. niphoclada*). Mesic floras of western Melville Island locally include *Oxytropis*, *Astragalus*, and a variety of more southerly Compositae as well as *Epilobium latifolium*, although these species may have greatly stunted flowering-stalks (Edlund 1986B, 1987A,B).

The "enriched zone" of west-central Ellesmere Island is similarly enhanced (Bruggemann and Calder 1953; Brassard and Beschel 1968; Soper and Powell 1983; Bridgland and Gillett 1984). No Leguminosae are present, but six species of shrubs, (*Salix herbacea*, *S. polaris*, *S. reticulata*, *Rhododendron lapponicum*, *Vaccinium uliginosum* and *Empetrum nigrum*) are found in a few sites (Porsild 1964; Porsild and Cody 1980).

These disjunct enriched zones (Figure 2) roughly correspond to anomalously warm areas (Figure 1) where temperature ranges overlap with those of the Dwarfed and Prostrate Shrub Zone, with mean July temperatures of at least 5°C. These areas may represent outliers of the warmer Dwarfed and Prostrate Shrub Zone, since most other associated species thrive there. Low, erect shrub species may not have been dispersed into these areas.

These "enriched areas" also show enhanced growth and diversity in wetland, aquatic and emergent species. More southerly species such as *Carex membranacea*, *Hippuris vulgaris*, and *Ranunculus gmelini* occur in both areas, while *Arctophila fulva* and *Caltha palustris* occur only in southwestern Melville Island.

The Prostrate Shrub Zone extends from the south side of Parry Channel, well into the Queen Elizabeth Islands. The 4°C mean July isotherm roughly coincides with the northern limit of woody-plant dominance, and with the northern limit of sedge dominance in wetlands.

Prostrate Shrub-Herb Transition Zone

Woody plants are present but no longer dominant in regions with mean July temperatures below 4°C. They are replaced by herbs, generally those that were most common in plant communities in the Prostrate Shrub Zone to the south. This transition zone, bracketed by the 4° and 3°C mean July isotherms, contains between 35 and 75 vascular plant species, including only two woody species. *Salix arctica* and *Dryas integrifolia* are generally restricted to sunny, sheltered locations. The common growth-form of *Salix* *arctica* is extremely compact (Figure 8).

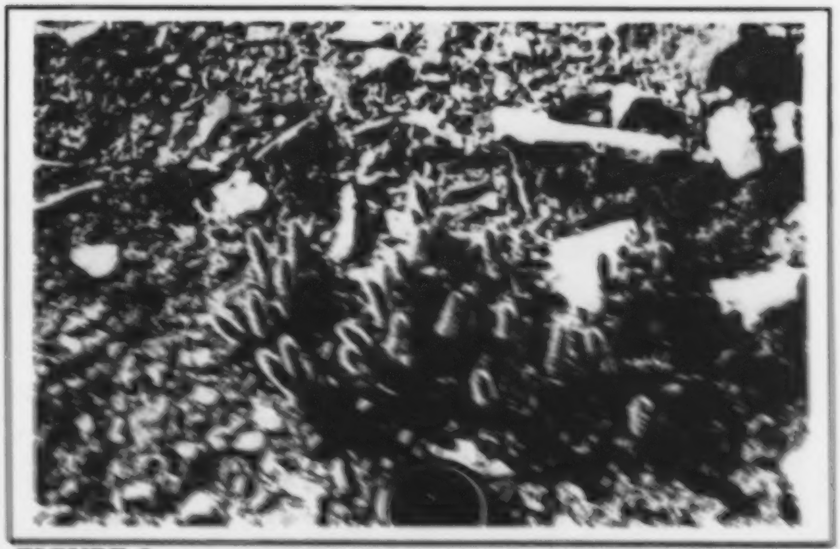


FIGURE 8: The compact form of *Salix arctica* near its northern limit on Melville Island. The branching extent is less than 10 cm.

A major change in composition also occurs in wetlands. There are only 11 wetland, aquatic and emergent species. Sedges, while present, are no longer dominant. Vascular wetland plants are restricted primarily to grasses, such as *Alopecurus alpinus* and *Dupontia fisheri*, as well as some herbs. Only a few emergent species such as *Pleuropogon sabinei* and *Ranunculus hyperboreus* survive in this zone.

This zone is found primarily in the north-central and northern Queen Elizabeth Islands. The 3°C mean July isotherm roughly coincides with both the northern limit of this zone and with the northern limit of the presence of woody plants. This boundary also marks the northern limit of sedges.

Herbaceous Zone

Vascular plant assemblages are entirely herbaceous in regions where mean July isotherms fall below 3°C. This zone is found in the northwestern and north-central Queen Elizabeth Islands and extends to their northern margins (Edlund 1980, 1983A). Neither woody plants, sedges, members of the Compositae nor aquatic or emergent species occur in this zone. The total vascular plant diversity is less than 35 species. There are no true wetland species in this zone; four vascular species grow on saturated soils, but these occur on somewhat drier habitats as well.

APPLICATIONS OF ARCTIC VEGETATION ZONATION

Few detailed paleoenvironmental reconstructions have been attempted north of treeline in Arctic Canada, perhaps because the tree growth-form is the most northerly well-known bioclimatic indicator. However, several arctic vegetation patterns can be roughly linked to mean July isotherms as in the northern boreal forest and treeline.

Many vascular-plant species show promise as bioclimatic indicators that can assist in extrapolating modern summer climate data into treeless regions where there are no climate records. This link can also assist in paleoenvironmental reconstructions in a treeless environment, for many plant macrofossils preserved in organic deposits and sediments are the same species that serve as bioclimatic indicators today.

Woody plants are one of the most useful bioclimatic indicators throughout the Arctic, even though the tree growth-form is absent. The presence of coniferous krummholz is, in itself, a useful indicator of climatic conditions close to those found near the coniferous treeline, roughly corresponding to the 10°C mean July isotherm. The small-tree growth-form of several deciduous shrubs, such as *Betula*, *Alnus* and *Salix* also indicates that treeline climatic conditions occur at least locally.

Where tree growth-forms are absent, treeline climatic conditions may also be indicated by the presence of several more temperate woody species such as: *Juniperus communis*, *Amelanchier alnifolia*, *Spirea beauverdiana*, *Myrica gale*, several *Ribes*, *Ledum groenlandicum*, *Rosa accicularis*, *Rubus strigosus*, *Potentilla fruticosa*, *Linnaea borealis*, and shrubby *Salix* species.

In the Arctic Islands the presence of shrubs with low, erect growth-forms (e.g. *Salix alaxensis*, *S. glauca*, *S. lanata*, *S. niphoclada*, *Ledum decumbens*, *Betula glandulosa*, and a variety of ericaceous species) indicates a climate comparable to the warmest sector of the Arctic - the denser and higher the thickets, the warmer the summer climate.

The trend of increasing restriction of low, erect thicket-growth to sheltered, well-watered places with decreasing temperatures (from 10° to 7°C) is similar to the pattern displayed by trees in the Forest-Tundra Transition Zone. The northern limit of low, erect shrubs roughly corresponds to the 7°C mean July isotherm, and is the southern Arctic equivalent of the northern forest limit.

The climatic dwarfing of willows, the deciduous equivalent of coniferous krummholz, is an indicator of regional mean July temperatures ranging from 7° to 5°C. The northern limit of species capable of erect shrub-growth roughly corresponds to the 5°C mean July isotherm, and is the southern Arctic equivalent of treeline.

Prostrate shrubs thrive from the northern limit of coniferous forest. They are important, often dominant, species throughout most of the Canadian Arctic Archipelago. In regions with mean July temperatures above 5°C, the branches of *Salix arctica* may spread out to a metre or more. The diameter of *Salix arctica* clumps decreases dramatically as mean July temperatures decrease below 5°C. Prostrate and matted shrubs lose their dominance when regional mean July temperatures drop below 4°C. The northern limit of woody plant dominance (the northern Arctic equivalent of the northern forest-limit) roughly corresponds to the 4°C mean July isotherm. Prostrate and matted shrubs persist locally into regions cooler than 4°C, but their growth-forms are extremely compact. Clumps of *Salix arctica* may be no more than 10 cm in diameter. The northern limit of woody plants roughly corresponds to the 3°C mean July isotherm, which can be considered the northern Arctic equivalent of treeline.

Wetlands, too, have several obvious bioclimatic indicators. A great diversity of wetland, aquatic and emergent species suggests conditions that occur today in the warmest zones of the Arctic. The presence of extensive *Eriophorum* tussock-tundra suggests mean July temperatures of at least 5°C. The presence of low, erect shrubs in the tussock-tundra would indicate mean July temperatures of at least 7°C. The dominance of sedge species in wetlands indicates mean July temperatures of at least 4°C, and the mere presence of sedges indicates mean July temperatures of at least 3°C.

With further research we should be able to refine and discover more bioclimatic indicators.

REFERENCES

Atmospheric Environment Service. 1982. Canadian climate normals 1951-1980: temperature and precipitation - the North - Y.T. and N.W.T. Environment Canada, Downsview. 55 pp.

Bliss, L.C. 1975. Tundra grasslands, herblands, and shrublands and the role of herbivores. Geoscience and Man 10:51-79.

Bliss, L.C. (Editor). 1977. Truelove Lowland, Devon Island, Canada: a High Arctic ecosystem. University of Alberta Press. Edmonton. 714 pp.

Brassard, G.R. and R.E. Beschel. 1968. The vascular flora of Tanquary Fiord, northern Ellesmere Island, N.W.T. Canadian Field-Naturalist 82(2):103-113.

Bridgland, J. and J.M. Gillett. 1984. Vascular plants of the Hayes Sound region, Ellesmere Island, Northwest Territories. Canadian Field-Naturalist 97:279-292.

Bruggemann, P.F. and J.A. Calder. 1953. Botanical investigations in northeast Ellesmere Island, 1951. Canadian Field-Naturalist 67(4):157-173.

Bryson, R.A. 1966. Air masses, streamlines, and the boreal forest. Geographical Bulletin 8(3):228-269.

Edlund, S.A. 1980. Vegetation of Lougheed Island, District of Franklin. Geological Survey of Canada, Paper 80-1A:329-333.

______. 1982A. Plant communities on the surficial materials of north-central Keewatin. Geological Survey of Canada, Paper 82-33:1-20.

______. 1982B. Vegetation of Cornwallis, Little Cornwallis and associated islands, District of Franklin. Geological Survey of Canada, Open File Map 857.

______. 1982C. Vegetation of Melville Island, District of Franklin: eastern Melville Island and Dundas Peninsula. Geological Survey of Canada, Open File Map 852.

______. 1983A. Bioclimatic zonation in a High Arctic region: central Queen Elizabeth Islands. Geological Survey of Canada, Paper 83-1A:381-390.

______. 1983B. Reconnaissance vegetation studies on western Victoria Island, Canadian Arctic Archipelago. Geological Survey of Canada, Paper 83-1B:75-81.

______. 1983C. Vegetation of the Bathurst Island area, Northwest Territories. Geological Survey of Canada, Open File Map 888.

______. 1983D. Vegetation of north-central Queen Elizabeth Islands, Northwest Territories. Geological Survey of Canada, Open File Map 887.

______. 1986A. Modern arctic vegetation distribution and its congruence with summer climate patterns. In: Proceedings of Atmospheric Environment Service Workshop: Impact of Climate Change on the Canadian Arctic. Edited by: H.M. French. Atmospheric Environment Service, Downsview. pp. 84-99.

______. 1986B. Vegetation-geology-climate relationships of western Melville Island, District of Franklin. Geological Survey of Canada, Paper 86-1A:719-726.

______. 1987A. Plants: living weather stations. Geos 16(2):9-13.

Edlund, S.A. 1987B. Vegetation of Melville Island, District of Franklin, Northwest Territories: western Melville Island. Geological Survey of Canada, Open File Map 1509.

Edlund, S.A. and P.A. Egginton. 1984. Morphology and description of an outlier population of tree-sized willows on western Victoria Island, District of Franklin. Geological Survey of Canada, Paper 84-1A:279-285.

Energy, Mines and Resources Canada. 1973. Vegetation regions. In: National Atlas of Canada. Queens Printer, Ottawa. pp. 45-46.

Gilbert, H. and S. Payette. 1982. Écologie des populations d'aulne vert (*Alnus crispa* (Ait.) Pursh) à la limite des forêts, Québec Nordique. Géographie physique et Quaternaire 36(1-2):109-124.

Gill, D. 1973. Ecological modifications caused by removal of tree and shrub canopies in the Mackenzie Delta. Arctic 26(2):95-111.

Hare, F.K. 1970. The tundra climate. Transactions of the Royal Society of Canada, 4th Series 8:393-399.

Maycock, P.F. and B. Matthews. 1966. An arctic forest in the tundra of northern Ungava, Quebec. Arctic 19(2):114-144.

Nordenskjöld, O. and L. Mecking. 1928. The geography of the polar regions. American Geographical Society, Special Publication No. 8:1-359.

Polunin, N. 1951. The real Arctic: suggestions for its delimitation, subdivision and characterization. Journal of Ecology 39:308-315.

______. 1960. Introduction to plant geography and some related sciences. McGraw-Hill, New York. 640 pp.

Porsild, A.E. 1964. Illustrated flora of the Canadian Arctic Archipelago. National Museums of Canada, Bulletin 146:1-218.

Porsild, A.E. and W.J. Cody. 1980. Vascular plants of the continental Northwest Territories. National Museums of Canada, Ottawa 667 pp.

Rannie, W.F. 1985. Summer air temperature and number of vascular species in Arctic Canada. Arctic 39(2):133-137.

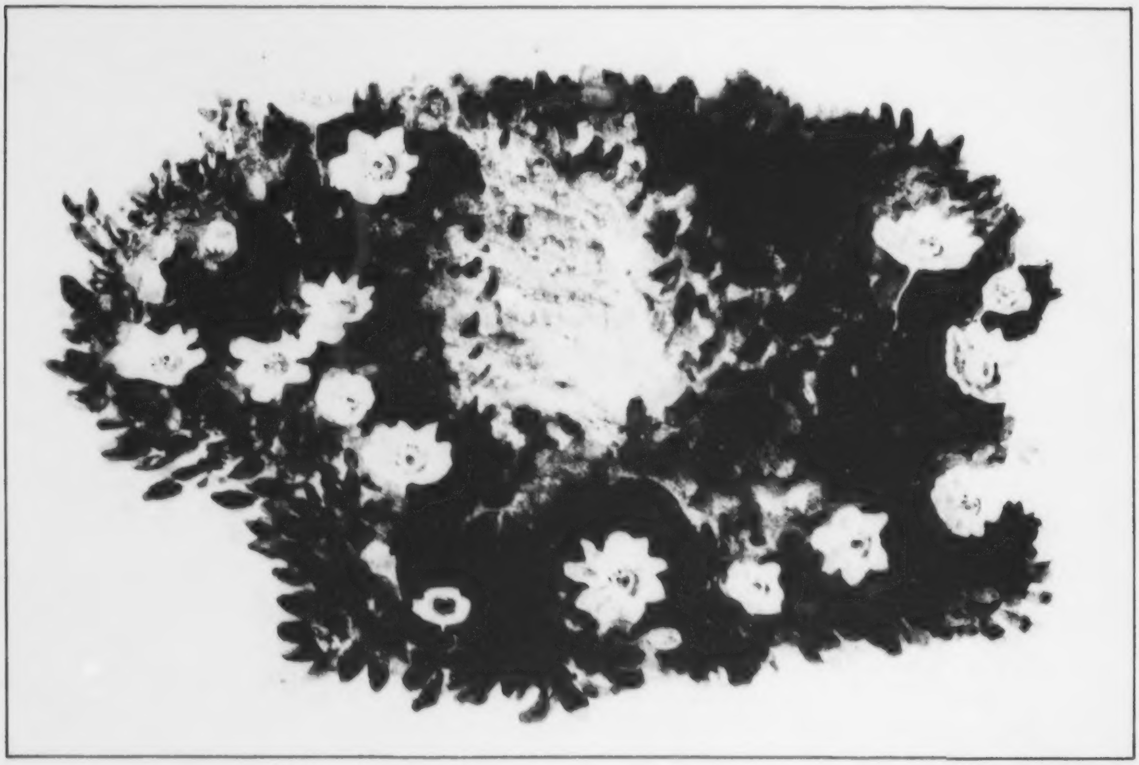
Richard, P.J.H. 1987. Le couvert végétal au Québec - Labrador et son histoire postglaciaire. Notes et Documents, Département de géographie, Université de Montréal No. 87-101:1-59.

Ritchie, J.C. 1984. Past and present vegetation on the far Northwest of Canada. University of Toronto Press, Toronto. 251 pp.

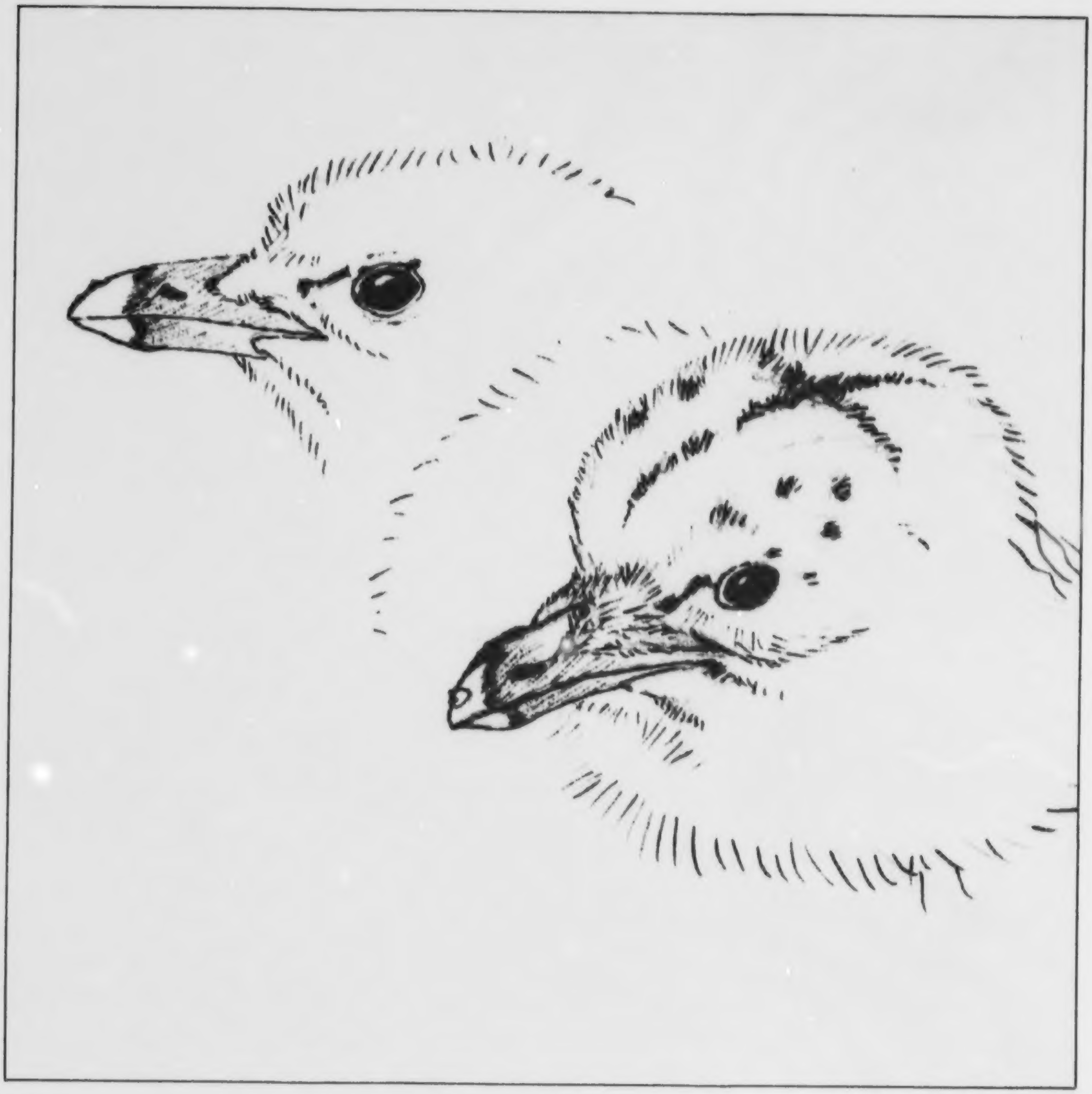
Rowe, J.S. 1972. Forest regions of Canada. Canadian Forestry Service, Publication 1300:1-172.

Soper, J.H. and J.M. Powell. 1983. Botanical studies in the Lake Hazen region, northern Ellesmere Island, Northwest Territories, Canada. National Museums of Canada, Publications in Natural Sciences No. 5:1-67.

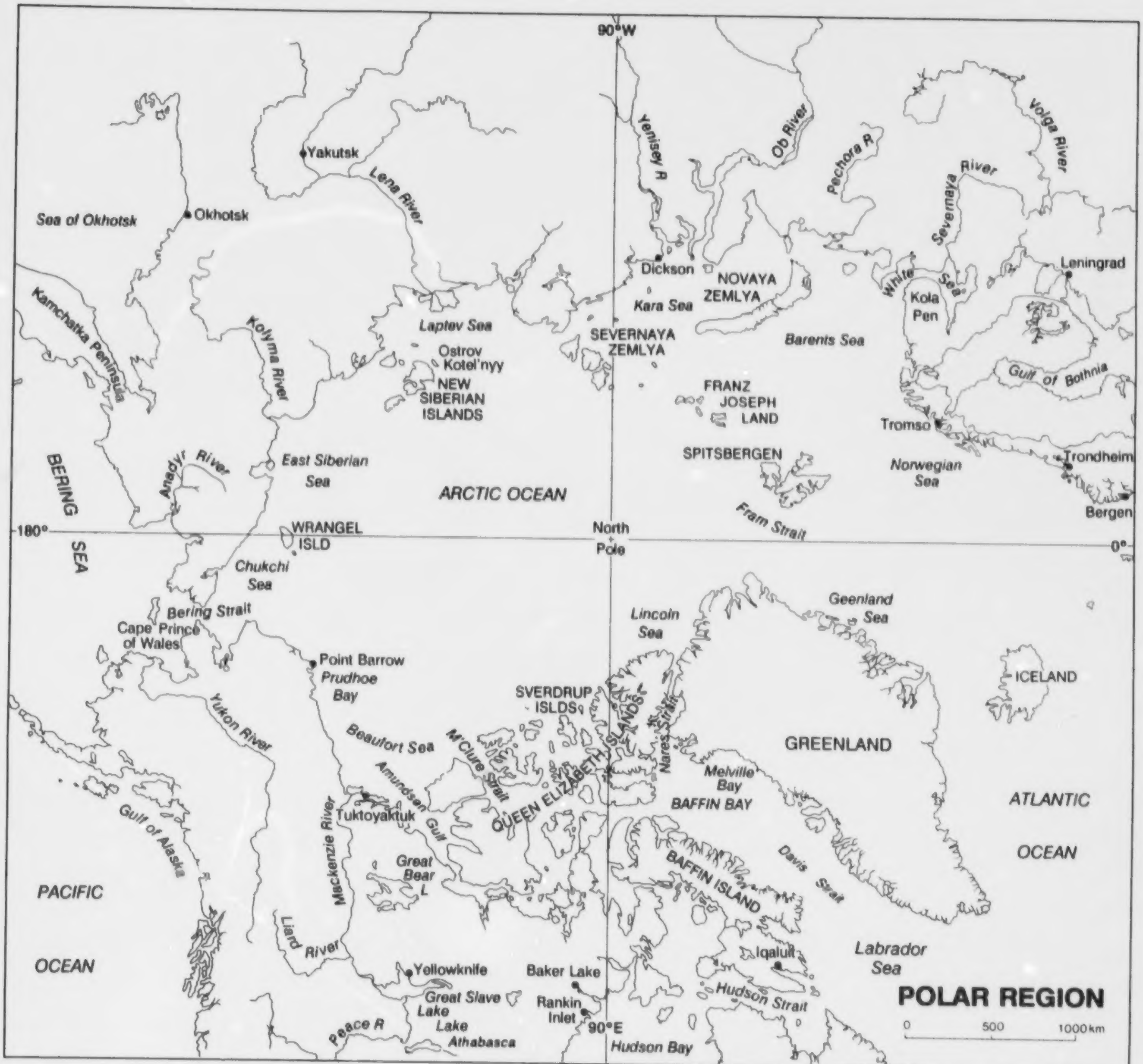
Young, S.B. 1971. The vascular flora of St. Lawrence Island, with special reference to floristic zonation in the arctic regions. Contributions from the Gray Herbarium, No. 201:11-115.



Illustrated by Brenda Carter



Illustrated by Brenda Carter


90°W
Yakutsk
Lena River
Okhotsk
Sea of Okhotsk
Yenisey R
Ob River
Pechora R
Volga River
Severnaya River
Leningrad
Dickson
NOVAYA ZEMLYA
Kara Sea
White Sea
Kola Pen
Kamchatka Peninsula
Kolyma River
Laptev Sea
Ostrov Kotel'nyy
NEW SIBERIAN ISLANDS
SEVERNAYA ZEMLYA
Barents Sea
Gulf of Bothnia
FRANZ JOSEPH LAND
Tromso
SPITSBERGEN
Norwegian Sea
Trondheim
Bergen
BERING SEA
Anadyr River
East Siberian Sea
ARCTIC OCEAN
Fram Strait
180°
WRANGEL ISLD
North Pole
0°
Chukchi Sea
Bering Strait
Cape Prince of Wales
Lincoln Sea
Geenland Sea
Point Barrow
Prudhoe Bay
SVERDRUP ISLDS
ICELAND
Yukon River
Beaufort Sea
M'Clure Strait
QUEEN ELIZABETH ISLANDS
Nares Strait
GREENLAND
Melville Bay
BAFFIN BAY
Amundsen Gulf
Tuktoyaktuk
ATLANTIC OCEAN
Gulf of Alaska
Mackenzie River
Great Bear L
Davis Strait
BAFFIN ISLAND
PACIFIC OCEAN
Liard River
Labrador Sea
Iqaluit
Yellowknife
Baker Lake
Hudson Strait
Great Slave Lake
Rankin Inlet
Peace R
Lake Athabasca
90°E
Hudson Bay
POLAR REGION
0
500
1000 km

Cartography by J.R. Weber and E.R. Maahs, Geological Survey of Canada, Geophysics Division

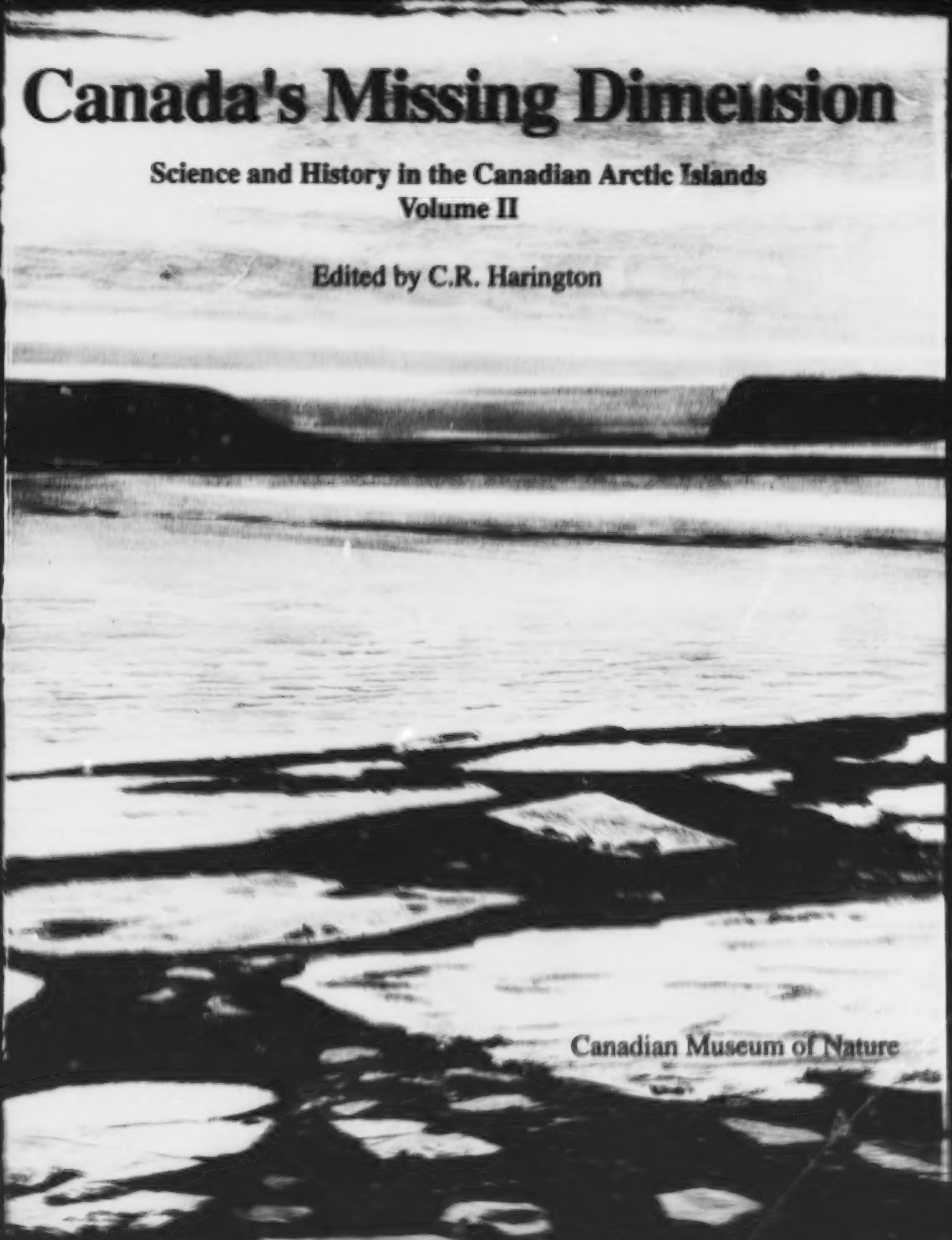
Canadian Museum
of Nature

Musée canadien
de la nature

Canada

Volume

2



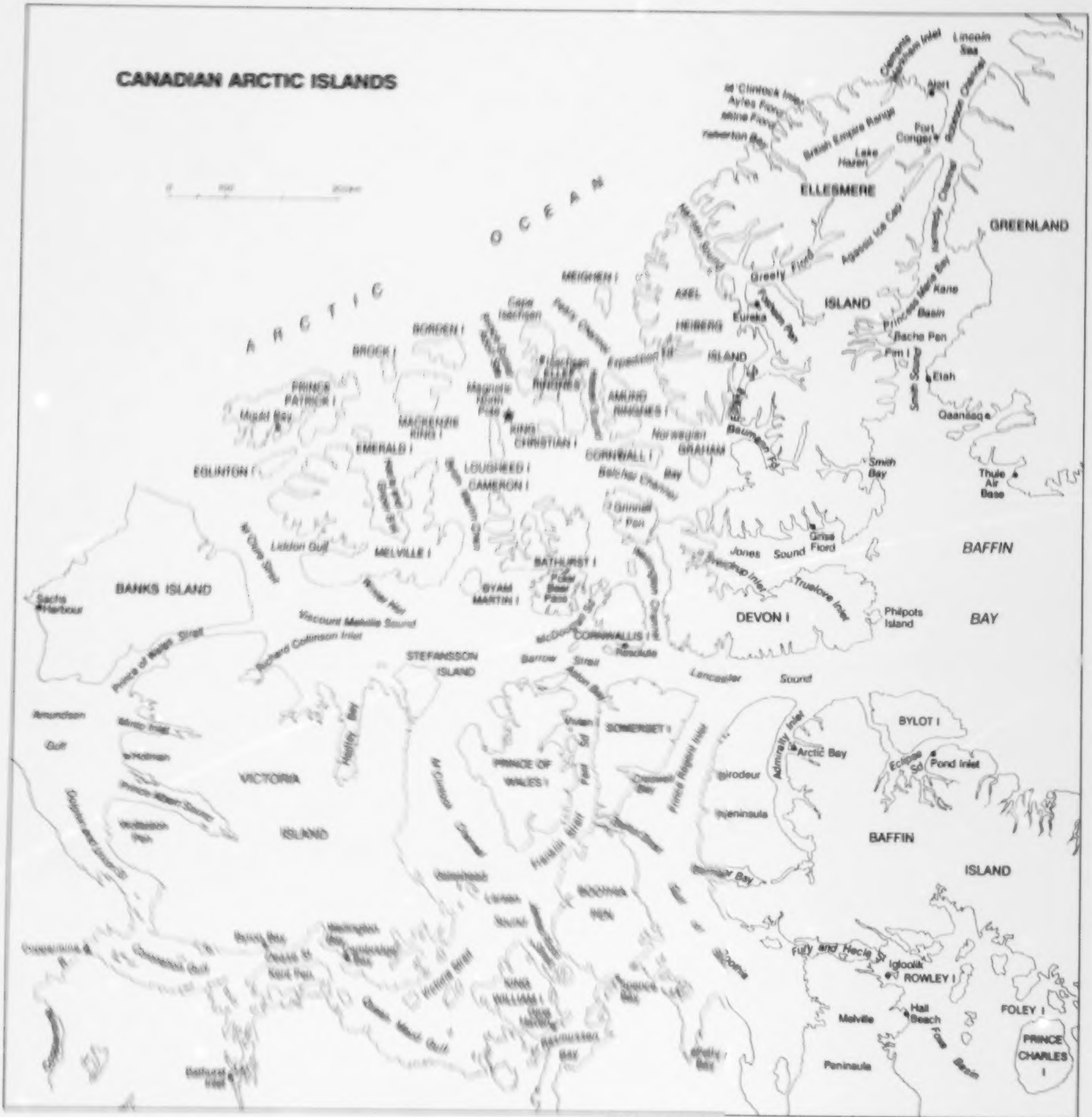
Canada's Missing Dimension

Science and History in the Canadian Arctic Islands
Volume II

Edited by C.R. Harington

Canadian Museum of Nature

CANADIAN ARCTIC ISLANDS


ARCTIC OCEAN
ELLESMERE ISLAND
GREENLAND
Lincoln Sea
Alert
Fort Conger
Lake Hazen
British Empire Range
Ayles Fiord
Greely Fiord
Agassiz Ice Cap
Kane Basin
Bache Pen
Pim I
Etah
Smith Sound
Qaanaaq
Thule Air Base
Eureka
AXEL HEIBERG ISLAND
MEIGHEN I
Cape Isachsen
BORDEN I
BROCK I
PRINCE PATRICK I
Mould Bay
MACKENZIE KING I
Magnetic North Pole
KING CHRISTIAN I
AMUND RINGNES I
CORNWALL I
Norwegian Bay
GRAHAM I
Belcher Channel
Grinnell Pen
EMERALD I
EGLINTON I
LOUGHEED I
CAMERON I
Liddon Gulf
MELVILLE I
BATHURST I
Polar Bear Pass
BYAM MARTIN I
BANKS ISLAND
Sachs Harbour
Viscount Melville Sound
Prince of Wales Strait
Richard Collinson Inlet
STEFANSSON ISLAND
CORNWALLIS I
Resolute
Barrow Strait
Jones Sound
Grise Fiord
Truelove Inlet
DEVON I
Philpots Island
BAFFIN BAY
Lancaster Sound
Smith Bay
Amundsen Gulf
Holman
VICTORIA ISLAND
Hadley Bay
PRINCE OF WALES I
SOMERSET I
Prince Regent Inlet
Admiralty Inlet
Arctic Bay
Brodeur Pen
BYLOT I
Pond Inlet
Eclipse Sd
BAFFIN ISLAND
Franklin Strait
BOOTHIA PEN
Victoria Strait
KING WILLIAM I
Rasmussen Bay
Queen Maud Gulf
Coronation Gulf
Coppermine R
Bathurst Inlet
Fury and Hecla St
Igloolik
ROWLEY I
Hall Beach
Foxe Basin
Melville Peninsula
FOLEY I
PRINCE CHARLES I

Cartography by J.R. Weber and E.R. Maahs, Geological Survey of Canada, Geophysics Division

Canada's Missing Dimension

Science and History in the Canadian Arctic Islands

Volume II

Edited by C.R. Harington

Published by: Canadian Museum of Nature

Shell Canada Limited

Petro-Canada Inc.

Polar Continental Shelf Project

© 1990 Canadian Museum of Nature

Published by the:

Canadian Museum of Nature
Ottawa, Canada K1P 6P4

Catalogue No. NM98-13/2-1990E

Available by mail order from:

Canadian Museum of Nature
Direct Mail Section
P.O. Box 3443, Station "D"
Ottawa, Canada K1P 6P4

Printed in Canada

ISBN: 0-660-13054-8

Cover: Cape Clarence, Somerset Island
Painting by Brenda Carter, Merrickville, Ontario

Brenda Carter sketches: title page, pages 21, 40, 53, 54, 90, 104, 130, 152, 160, 186, 254, 258, 271, 272, 293, 326, 404, 420, 441, 442, 470, 510, 513, 543, 567, 589, 607, 632, 664, 676, 694, 742, 767, 792, 805, 834

© 1990 Musée canadien de la nature

Publié par le :

Musée canadien de la nature
Ottawa, Canada K1P 6P4

No de catalogue NM98-13/2-1990E

L'editeur remplit les commandes postales adressées au :

Musée canadien de la nature
Section des commandes postales
C.P. 3443, Succursale D
Ottawa, Canada K1P 6P4

Imprimé au Canada

ISBN: 0-660-13054-8

Peinture de la couverture : Cap Clarence, Île Somerset, de Brenda Carter (Merrickville, Ontario)

Esquisses de Brenda Carter : page titre, p. 21, 40, 53, 54, 90, 104, 130, 152, 160, 186, 254, 258, 271, 272, 293, 326, 404, 420, 441, 442, 470, 510, 513, 543, 567, 589, 607, 632, 664, 676, 694, 742, 767, 792, 805, 834

CONTENTS

Volume I

ACKNOWLEDGEMENTS 1

INTRODUCTION 6

C.R. Harington

SCIENTIFIC RESEARCH: SUPPORT, CONFLICT AND THE FUTURE

Polar Continental Shelf Project 9
George D. Hobson

Conflict in Northern Activities 22
R.L. Christie

Scientific Research in the Canadian Arctic Islands - The Future 41
E.F. Roots

THE EARTH: FOSSILS AND PALEOENVIRONMENTS

Paleozoic Fishing - The Franklinian Grounds 55
D.L. Dineley

Mesozoic Vertebrates in Arctic Canada 81
Dale A. Russell

Terrestrial Vertebrates from the Tertiary of Canada's Arctic Islands 91
Mary R. Dawson

New Data on the Late Tertiary Beaufort Formation: Plant and Insect Fossils from Prince Patrick Island, N.W.T. 105
John V. Matthews, Jr., L.E. Ovenden, and J.G. Fyles

Ice Age Vertebrates in the Canadian Arctic Islands 140
C.R. Harington

Rates of Decay of Mammalian Remains in the Permafrost Environment of the Canadian High Arctic 161
Antony J. Sutcliffe

FRESHWATER, SEA AND ICE

A Unique Lake in Canada's High Arctic 188
M. Dickman, A.G. Lewkowicz, and J. Price

Ice/Water Interactions and Their Effect on Biological Oceanography in the Arctic Archipelago 204
Robert J. Conover, Glen F. Cota, W. Glen Harrison, Edward P.W. Horne, and Ralph E.H. Smith

Surface Topography, Thickness and Ice Core Studies of Multiyear Landfast Sea Ice and Ward Hunt Ice Shelf, Northern Ellesmere Island, N.W.T. 229
Martin O. Jeffries, H. Roy Krause, William M. Sackinger, and Harold V. Serson

Acoustic Research on Sounding through Sea Ice and Iceberg Detection in the Canadian Arctic 255
Phillipe de Heering

Arctic Ice Cores: Putting Present Climate into Perspective 265
Roy M. Koerner

THE ATMOSPHERE

Climate and the Canadian Arctic Islands 273
Gordon A. McKay

The Queen Elizabeth Islands: A Case Study for Arctic Climate Data Availability and Regional Climate Analysis 294
Bea Taylor Alt and Barrie Maxwell

L'Exposition des Plaques de Neige Résiduelles dans l'Arctique Canadien 327
Daniel Lagarec, Bernard Lauriol et Daniel Devocht

Arctic Meteorology and Climatology, Present State and Future Direction 337
Claude L. Labine

THE PLANTS

High Arctic Ecosystems: How They Develop and Are Maintained 350
L.C. Bliss

Lichens in the Canadian Arctic Islands 385
John W. Thomson

Bioclimatic Zones in the Canadian Arctic Archipelago 421
S.A. Edlund

Volume II

INSECTS

Arctic Insects: Instructive Diversity 444
H.V. Danks

Crane Flies (Diptera:Tipulidae) of the Arctic Islands 471
Fenja Brodo

Energy Budget for Activity and Growth of a High Arctic Insect, Gynaephora groenlandica (Wocke) (Lepidoptera:Lymantriidae) 485
Olga Kukal

FISHES, BIRDS AND MAMMALS

Priorities for Ichthyological Research in the Canadian Arctic Archipelago 512
Don E. McAllister

Avian Zoogeography in the Canadian Arctic Islands 516
Henri Ouellet

Migration, Body Condition and Behaviour of Shorebirds during Spring Migration at Alert, Ellesmere Island 544
R.I.G. Morrison and N.C. Davidson

Winter Studies of Birds and Mammals in the Canadian Arctic Islands 568
David R. Gray

The Decline and Recovery of Caribou and Muskoxen on Victoria Island 590
Anne Gunn

Inter-Island Movements of Peary Caribou: A Review and Appraisement of Their Ecological Importance 608
Frank L. Miller

Muskox (Ovibos moschatus Zimmermann) Populations on the Northeastern Coast of Devon Island 633
Donald L. Pattie

Some Observations on the Nursing Behaviour of Arctic Hares (Lepus arcticus) 643
B.T. Aniškowicz, H. Hamilton, D.R. Gray, and C. Downes

HUMAN PREHISTORY

The Peopling of the Arctic Islands 666
Robert McGhee

Thule Pioneers in the Canadian Arctic 677
Charles D. Arnold and Karen McCullough

Prehistoric Thule Eskimo Whaling in the Canadian Arctic Islands: Current Knowledge and Future Research Directions 695
James M. Savelle and Allen P. McCartney

Environmental and Cultural Change in the Large Lakes Region of Baffin Island: A Progress Report 724
J.D. Jacobs, D.R. Stenton, and W.N. Mode

HISTORY AND RECENT EXPEDITIONS

Discoveries and Explorations of the Circumpolar Lands and Seas from Antiquity to the Twentieth Century 744
J.R. Weber and E.F. Roots

Emile Frédéric de Bray and His Role in the Royal Navy's Search for Franklin, 1852-1854 768
William Barr

The 1983 Ellesmere Island Arctic Expedition 793
Tim O. Rockwell

Exploratory Mountaineering in the Arctic Islands 806
G.V.B. Cochran

INDEX 835

INSECTS

ARCTIC INSECTS: INSTRUCTIVE DIVERSITY

H.V. Danks[1]

Abstract: Although the terrestrial arthropod fauna of the Arctic is much less diverse than that of temperate areas, about 860 species in 150 families have been reported from the Canadian Arctic Islands. Many others await discovery or description. More than 550 species occur even in the Queen Elizabeth Islands. Many characteristics of these arctic insects have evident adaptive advantages in environments with short, cool, unpredictable summers and long cold winters. The composition of the fauna, and its habitat and trophic characteristics are closely related to the availability of resources. Most northern arthropods are saprophages, predators, or ectoparasites of vertebrates. Most species are confined to superficial soil and shallow waters warmed by the sun, or to the skin of warm-blooded hosts. Although arctic habitat-structure and food supply for insects therefore are limited relative to temperate situations, the diversity of insects and of their adaptations is very instructive. There are many interactions between arthropods and vertebrates, other invertebrates and plants; and resources are transferred between different habitats. Therefore, the biotic communities of the Canadian Arctic Islands are surprisingly complex.

Résumé: Malgré une diversité nettement plus restreinte par rapport à ce qui est observé dans les régions tempérées, les arthropodes terrestres de l'Arctique canadien comptent près de 860 espèces regroupées en 150 familles. Il en reste beaucoup d'autres à découvrir ou décrire. Plus de 550 espèces sont trouvées même dans les îles Reine-Elisabeth. Ces insectes ont nombre de caractéristiques offrant des avantages sur le plan de l'adaptation à un milieu aux étés courts, frais et imprévisibles ainsi qu'aux longs hivers froids. La composition faunique, l'habitat et les caractéristiques trophiques sont liés de près à la disponibilité des ressources. La plupart des arthropodes septentrionaux sont des saprophages, des prédateurs ou des ectoparasites de vertébrés. La plupart des espèces sont confinées à la couche superficielle du sol et aux eaux peu profondes réchauffées par le soleil ou encore à la peau d'hôtes à sang chaud. Bien que la structure des habitats arctiques et que les sources alimentaires imposent des contraintes additionnelles par rapport à la situation en zone tempérée, la diversité des insectes et leurs adaptations sont fort révélatrices. Il existe beaucoup d'interactions entre les arthropodes et les vertébrés, les autres invertébrés et le monde végétal, et les ressources sont transférées d'un habitat à l'autre. Les communautés d'êtres vivants de l'archipel arctique ont donc une complexité étonnante.

INTRODUCTION

Terrestrial arthropods, the spiders, mites, springtails, etc., and especially the insects, are the most diverse macroscopic organisms in non-marine ecosystems everywhere. More than 2,000 species of terrestrial arthropods are known from regions beyond the northern limit of trees in North America, and as many more are anticipated to await discovery or description (Danks 1981). Although much more limited than in temperate regions, such diversity provides unrivalled opportunities to investigate how and why the composition of northern faunas is modified relative to more southern regions, how the successful arctic species are adapted, and how northern ecosystems function.

The Arctic Islands contain a more limited arthropod fauna than the North American Arctic as a whole because they lack many mainland elements and those that just enter

---

[1] Biological Survey of Canada (Terrestrial Arthropods), Zoology Division, National Museum of Natural Sciences, Ottawa, Ontario K1P 6P4

tundra habitats. The characteristically arctic species found in the islands provide especially instructive insights into Arctic ecological communities.

FAUNAL COMPOSITION AND DISTRIBUTION

About 860 species of terrestrial arthropods have been reported from the Arctic Islands, 660 of them named to species (Table 1). Based on knowledge of such faunas in Canada as a whole (Danks 1979), nearly 2,000 species might eventually be expected there. Final figures cannot currently be obtained, except in a few well-known groups such as mosquitoes, because specialized collecting has been sporadic, and difficult taxonomic problems remain in many groups (especially among the mites and parasitic Hymenoptera). Nearly three-quarters of the reported species are insects. The Queen Elizabeth Islands contain only 553 reported species of arthropods. By contrast, a well-known temperate area (Great Britain) of about the same size contains over 22,000 species of insects alone (Stubbs 1982).

The diversity of arthropods in the Arctic, therefore, is greatly reduced. Certain groups are much better represented than others (Table 2). Compared with tropical or temperate regions, for example, beetles (Coleoptera) are much less well-represented in the Arctic, whereas flies (Diptera) are very well-represented there (Table 3). A small number of families is characteristic: well over half the species of arthropods of the Arctic Islands belong to only about 25 of the 155 families present (Table 4); more than 910 families of terrestrial arthropods occur in Canada (Danks 1979). Such selective arctic representation occurs at all taxonomic levels, including the genus. It suggests generalizations, developed in later sections, about the habitats and ecology of species that are successful.

Well over half of the individual species of the Arctic Islands are Holarctic, occupying large expanses of similar terrain that characterize the northern high latitudes (Danks 1981). Both tundra specialists (e.g. Figure 1) and more widely distributed forms (e.g. Figure 2) occur there. Specific collecting has not been sufficiently systematic to discover if there are detailed patterns of occurrence or absence from one island to another. Such patterns would, in any case, depend on island size and other features. Moreover, most arctic insects are concentrated in "oases" (Babb and Bliss 1974) where topography and other factors ameliorate

TABLE 1: NUMBER OF NAMED SPECIES OF MAJOR GROUPS OF TERRESTRIAL ARTHROPODS REPORTED FROM CANADA AND ARCTIC REGIONS.

GROUP	NUMBER OF NAMED SPECIES			
	CANADA[1]	ARCTIC CANADA AND ALASKA[2]	CANADIAN ARCTIC ISLANDS[2]	QUEEN ELIZABETH ISLANDS[2]
Arachnida (spiders)	1,256	112	30	18
Acari (mites)	1,915	261	120	77
Collembola (springtails)	295?	97	49	44
Insecta (insects)	29,976	1,468	462	242
Total named species[3]	33,672	1,943	661	381
Minimum species present[4]	------	2,237	858	553

[1] Based on Danks (1979).

[2] Based on Danks (1981), with additions published through 1986, and this paper.

[3] Including minor groups not listed.

[4] Including additional reported, unnamed taxa.

TABLE 2: DIVERSITY OF TERRESTRIAL ARTHROPODS IN ARCTIC NORTH AMERICA.

GROUP	ARCTIC NORTH AMERICA		CANADIAN ARCTIC ISLANDS		QUEEN ELIZABETH ISLANDS	
	no. of genera	min. no. of spp.[1]	no. of genera	min. no. of spp.[1]	no. of genera	min. no. of spp.[1]
Arachnida	233	474	119	213	83	137
Araneae	54	117	19	30	13	18
Opiliones	1	1	0	0	0	0
Acari	178	354	99	179	69	117
Mesostigmata	34	76	20	45	13	29
Prostigmata	65	125	45	76	36	56
Acaridiae	7	7	3	3	3	3
Oribatei	72	146	31	55	17	29
Chilopoda	3	3	0	0	0	0
Protura	2	2	0	0	0	0
Collembola	49	110	29	61	27	55
Insecta	691	1,650	313	588	202	363
Ephemeroptera	11	22	1	3	0	0
Odonata	3	6	0	0	0	0
Plecoptera	13	20	3	3	0	0
Orthoptera[2]	4	6	1[4]	1[4]	1[4]	1[4]
Phthiraptera[3]	32	52	25	44	18	32
Hemiptera	43	66	17	18	6	6
Thysanoptera	5	5	3	3	3	3
Neuroptera	2	2	0	0	0	0
Coleoptera	86	203	21	30	9	13
Diptera	246	787	131	307	93	199
Siphonaptera	13	20	4	6	4	4
Lepidoptera	87	162	39	62	19	23
Trichoptera	20	25	3	3	1	1
Hymenoptera	124	272	63	106	47	80
Others[4]	2	2	2	2	1	1

[1] Minimum species includes named species, plus those reported as taxonomically distinct from named species within a genus, and species in genera without named species.

[2] Including Grylloptera.

[3] Based partly on host-ranges.

[4] Adventitious.

Sources as in Table 1.

TABLE 3: COMPOSITION OF THE INSECT FAUNA IN DIFFERENT REGIONS, TO SHOW CHANGES IN THE REPRESENTATION OF SELECTED ORDERS (BASED ON NAMED SPECIES REPORTED).

ORDER	PERCENTAGE OF REGIONAL FAUNA				
	WORLD[1]	NORTH AMERICA[1]	ARCTIC NORTH AMERICA[2]	CANADIAN ARCTIC ISLANDS[2]	QUEEN ELIZABETH ISLANDS[2]
(Total No. of Insect spp.)	(762,659)	(93,728)	(1,468)	(462)	(242)
Orthoptera	4	1	0.4	0.2[3]	0.4[3]
Phthiraptera	0.4	0.4	4[4]	9[4]	14[4]
Hemiptera	7	12	4	4	3
Coleoptera	39	32	13	6	3
Diptera	16	19	50	53	61
Lepidoptera	15	12	11	12	10
Hymenoptera	14	19	13	11	10

[1] Borror *et al.* (1981).
[2] Danks (1981) with additions through 1986, and this paper.
[3] Adventitious.
[4] Based partly on host-ranges.

TABLE 4: FAMILIES OF TERRESTRIAL ARTHROPODS CHARACTERISTIC OF THE CANADIAN ARCTIC ISLANDS[1].

TAXA	MINIMUM NUMBER OF SPECIES		
	ARCTIC NORTH AMERICA	CANADIAN ARCTIC ISLANDS	QUEEN ELIZABETH ISLANDS
Arachnida			
Erigonidae	39	15	13
Acari			
Ascidae	25	16	13
Rhagidiidae	14	11	6
Ceratozetidae[2]	26	11	5
Collembola			
Hypogastruridae	18	12	11
Isotomidae	45	27	26
Mallophaga			
Philopteridae	32	28	22
Hemiptera			
Aphididae	21	13	3
Diptera			
Tipulidae[2]	50	16	6
Chironomidae	157	108	94
Simuliidae	26	10	0
Mycetophilidae	15	10	9
Sciaridae	14	11	11
Anthomyiidae	139	28	6
Muscidae	162	48	21
Lepidoptera			
Papilionoidea (5 fams.)	54	21	7
Geometridae	22	9	2
Noctuidae	35	12	6
Hymenoptera			
Tenthredinidae	34	21	14
Braconidae	22	11	6
Ichneumonidae	162	60	49
Total (families listed)	1,112 (26)	498 (26)	330 (26)
Total (all families)	2,237 (341)	858 (155)	553 (118)

---

[1] Characteristic families are any that include more than 1% of the fauna of the islands.

[2] Figures revised from unpublished information assembled for the Ceratozetidae by V.M. Behan-Pelletier (personal communication) and for Tipulidae by F. Brodo (personal communication).

Sources as in Table 1.

local temperatures and moisture supply (Corbet 1972). These oases support rich sedge-moss meadows and associated faunas even in the High Arctic.

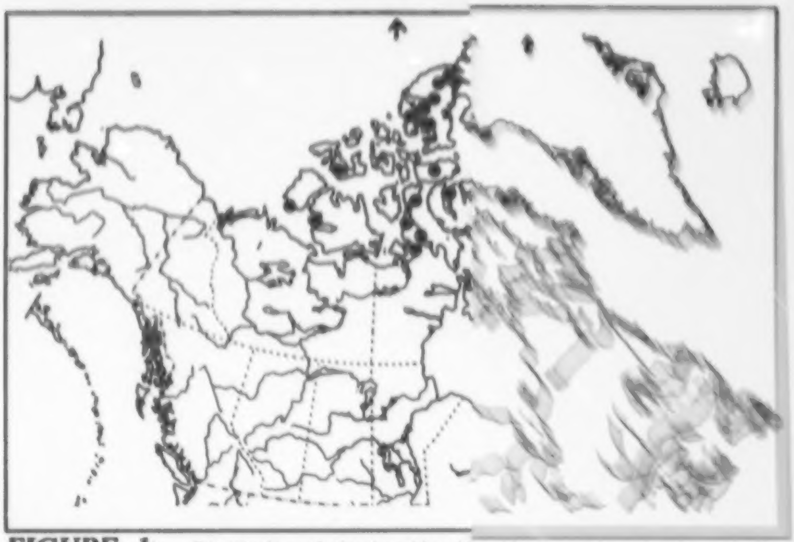


FIGURE 1: Distribution of the lycosid spider Alopecosa exasperans, a species confined to the northern Arctic (Danks 1981).

Some broad distributional patterns can be recognized within the islands. Faunas are especially impoverished in the northwestern archipelago, where low summer temperatures are associated with smaller island size and greater cloud-cover (Danks 1980; see Figures 1, 2). Southern Banks and Victoria islands in the west and southern Baffin Island in the east have richer vegetation (including shrubs that are absent further north), and a number of island species have been collected only in this southern "low arctic" zone (e.g. Figure 3). The southern richness and northwestern impoverishment of the fauna suggest that ecological, chiefly climatic, factors control a predominantly north-south zonation in the Canadian Arctic Islands. On the mainland, on the other hand, the influence of historical

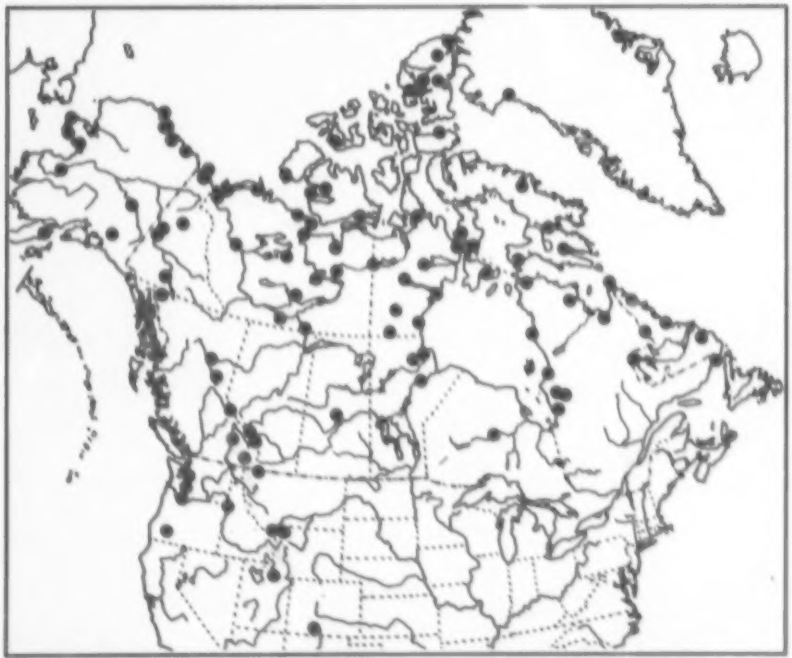


FIGURE 2: North American distribution of the mosquito Aedes impiger, a species found in arctic, alpine and boreal habitats (Danks 1981).

factors is easier to see because many east-west range limits coincide with the Mackenzie River and Hudson Bay (e.g. Figure 3), which are major dispersal-barriers for tundra forms. Some western forms extend to Banks Island.

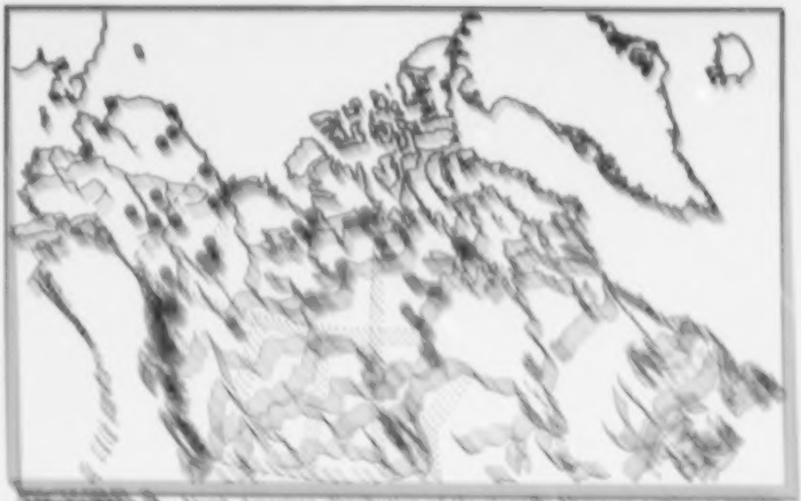


FIGURE 3. North American distribution of the sawfly [illegible], a species not entering the southern Canadian Arctic Islands, and confined to the west of Hudson Bay (Danks 1981).

ADAPTATIONS

Most northern species are clearly adapted to arctic conditions. The adaptations conform to the short, cool growing-season, to the limited diversity of habitats, and to other features of northern environments. Characteristic adaptations of arctic arthropods are listed in Table 5. However, some cosmopolitan arthropod species appear to occupy microsites in the surface soil that are relatively warm and moist - even in polar deserts (Addison 1975).

Colour and Structure

Arctic species commonly are darker than temperate relatives (Danks 1981, p. 266), usually because they contain the black pigment melanin. Such dark colours facilitate the absorption of solar heat. Therefore, arthropods tend to be darker northward, unlike vertebrates in which white (air-filled) pelage enhances insulation and white plumage or pelage provides camouflage in snow-covered terrain.

Some larger species such as bumble bees and some flies and caterpillars are especially hairy. The hairs allow solar radiation to warm the body, but prevent convective heat loss (Kevan et al. 1982).

Structures in several arctic species are reduced, usually because their functions are curtailed by the harsh conditions. For example, especially on the mainland some northern species of fungus gnats, midges, crane flies and moths are brachypterous (wings reduced) or

TABLE 5: SUMMARY OF ADAPTATIONS OF ARCTIC ARTHROPODS[1].

ADAPTATION	SUPPOSED ADVANTAGE	EXAMPLES
Colour and Structure		
Melanism	Solar heat gain in cool environments	Many insects
Hairiness	Conserves heat gained, in larger insects	Many insects
Robustness	Moisture conservation	Some ichneumonids
Reduced wings	Energy saved (flight limited by cool conditions)	Several flies, moths
Reduced eyes	Normally nocturnal forms are active in light in Arctic	Some noctuid moths
Reduced antennae of males	Detection of females during swarming flights is not necessary when flight is limited	Some chironomid midges
Small size	Species can use limited resources	Many species
Activity and Behaviour		
Selection of warm habitats for activity or progeny production	Activity allowed in cool environments in locally favourable sites	Most species
Selection of protected sites for overwintering (e.g. plant clumps)	Protection against cold or wind-driven snow	Many species (but some species overwinter fully exposed)
Low temperature thresholds for activity	Activity allowed in cool environments	Several species
Opportunistic activity	Activity whenever temperatures are permissive	Bumble bees, midges, etc.
Basking	Heat gain in sunshine	Many butterflies, etc.
Physiology and Metabolism		
Adjustment of metabolic rate	Life processes continue in cool environments	Some species of various groups
Resistance to cold	Survival during cold winters	All species
Resistance to starvation	Survival when food supplies are unpredictable	Some moth larvae, some springtails

TABLE 5: (cont'd)

ADAPTATION	SUPPOSED ADVANTAGE	EXAMPLES
Life-Cycles and Phenology		
Multi-year life-cycles	Life-cycle completed although resources are limited	Moth larvae, midge larvae, etc.
Rapid development	Life-cycle completed before winter supervenes	Mosquitoes, etc.
Abbreviation of normally complex life-cycles	Life-cycle completed before winter supervenes	Aphids, etc.
Earliest possible emergence in spring	Life-cycle completed before winter supervenes	Midges, etc.
Brief and synchronized reproductive activity	Life-cycle completed before winter supervenes	Many moths, etc.
Dormancy	Activity stops before damaging winter cold; individuals held dormant through summer to emerge as early as possible the next spring	Chironomid midges, etc.
Prolonged dormancy for more than one season	"Insurance" against a summer unsuitable for reproduction	Various species of flies, moths, sawflies, etc.
Food Range		
Autogeny (development of eggs without a blood-meal in biting flies)	Offsets shortage of hosts; or short season	Mosquitoes
Different foodplants	Survive although a particular foodplant is absent	Few species
Polyphagy	Survival despite low density of foods	Many species, especially saprophages/detritivores and predators
Genetic Adaptations		
Parthenogenesis	Reduces mating activity in harsh conditions; well-adapted genotypes [illegible]	Midges, black flies, [illegible], sawflies, scale insects, etc.

[1] See references in text and Danks (1981).

apterous (wings absent) - generally in the females (Downes 1962; Vockeroth 1972). The dynamics of dispersal or the need to move in sand and litter habitats can select for aptery, but in arctic forms the reduction of wings appears to be correlated chiefly with temperatures that often are below the threshold for flight activity. In some groups of nematocerous Diptera, forms with reduced antennae are found in the Arctic. Those groups normally mate in male swarms (Downes 1969), and females are detected in flight by the antennal sense organs of the males. In the Arctic, swarming of many species of chironomids is curtailed or eliminated, and some species have reduced antennae (Downes 1969; Oliver 1984).

Activity and Behaviour

Behavioural traits often are correlated with structural adaptations that must be interpreted through observations of living animals. For example, many arctic butterflies (Kevan and Shorthouse 1970; Kingsolver 1985), flies (Kevan 1973), bugs (Böcher 1972) and other arctic insects bask in sunshine especially on flowers, raising the body-temperature for activity (e.g. Roland 1982), and accelerating growth or the development of eggs (Corbet 1965, for mosquitoes). This type of basking behaviour is closely tied to the location of dark pigments. For example, some butterflies bask laterally to the sun's rays with their wings closed; the wings have melanic undersides. Some species open the wings and expose the dark uppersurfaces to the sun. Other butterflies expose the body, or settle on dark, warm substrates. Optimum temperatures for activity sometimes are high and narrowly limited, so that thermal regulation by behavioural means such as basking is surprisingly precise and effective (Sherman and Watt 1973). In other insects, however, activity can continue even when temperatures are low - down to 0°C in some midges and stoneflies.

Whether or not they have specialized basking behaviour, nearly all arctic arthropods, even those confined to widespread soil microsites, actively select the most favourable habitats. Moist, vegetated patches contain much higher populations of mites and springtails than the intervening barrens. High Arctic butterflies are active chiefly in a small number of sheltered, insolated depressions (Kevan and Shorthouse 1970). The finely-tuned responses of High Arctic mosquitoes result in the deposition of eggs only in the warmest sheltered south-facing sites, and only during the warmest part of the day (Corbet and Danks 1975). These sites first become free of snow the following spring, when the eggs hatch.

Most High Arctic insects show opportunistic daily activity whenever it is warm enough (Danks and Oliver 1972B), unlike their temperate relatives with temporally-fixed activities. Such behaviour allows the insects to take advantage of warm, calm periods at any time, although normally activity is greatest near midday when incoming solar radiation is highest (Fox and Stroud 1986).

Physiology and Metabolism

Some arctic species continue development at temperatures that would prevent development of typical temperate species. For example, threshold temperatures for development are only about 1°C in tundra mosquito larvae (Haufe and Burgess 1956); metabolic-rates at a given temperature apparently are higher in some arctic aquatic (but not terrestrial) forms compared to southern forms (Scholander *et al.* 1953). However, many arctic species have no such lower thresholds or higher rates of development, and they grow only during periods with relatively favourable conditions.

Particularly interesting physiological adaptations have been reported in some High Arctic caterpillars (*Gynaephora* species: Ryan and Hergert 1977; Kukal, this volume) and springtails (*Hypogastrura "tullbergi"*: Addison 1977 - actually *H. concolor* : Fjellberg 1986). Individuals of these species can survive for a whole summer virtually without feeding, allowing them to overcome temporary shortages of scattered food resources.

All arctic species resist cold. Many polar mites and springtails supercool, remaining unfrozen even at very low temperatures (Block and Sømme 1982; Sømme 1981). Most High Arctic insects are freezing-tolerant, surviving extracellular ice formation in the tissues. Many can survive low temperatures during spring and fall activity, as well as during prolonged winter dormancy. Nevertheless, survival while frozen is temperature- and time-dependent (Danks 1978). Arthropod cold-hardiness depends on the build-up of cryoprotectants, usually polyhydric alcohols such as glycerol, but also in some species macromolecules such as peptides. However, the cold-hardiness of relatively few arctic species has been investigated in detail (Ring 1981, 1983). Different species have different mechanisms of cold-hardiness. Cold-hardiness also tends to give resistance to anoxia and desiccation.

Life Cycles and Phenology

In markedly seasonal environments, development coincides with suitable conditions through various linked adaptations that control: (1) the time taken to complete a generation; (2) the seasonal position of active, especially reproductive, stages; and (3) the onset and completion of dormancy.

Some species develop very slowly in the Arctic where heat and food are limited. Few High Arctic species complete a generation in a single year. For example, up to 14 years are required in the moth *Gynaephora groenlandica* (Kukal and Kevan 1987), 7 years in two *Chironomus* species (Butler 1982), 6-8 years in the crane fly *Tipula carinifrons* (Lantsov 1982), 6-7 years in spiders (Leech 1966), and perhaps many years in some species of mites (Ryan 1977). Such long-lived species pass the winter in early stages, continuing to feed the following year.

Other species, especially those from warm shallow ponds or other warm insolated microsites, develop rapidly, and even in the Arctic are univoltine - completing a generation each year. Arctic mosquitoes develop from egg to egg (Corbet and Danks 1973); arctic aphids (W.R. Richards 1963), bumble bees (K.W. Richards 1973), and other species (e.g. MacLean 1983) also are univoltine.

Because the arctic summer is so short, most arctic insects emerge at the earliest opportunity in spring, and reproduce rapidly before winter returns. Although different species appear at somewhat different intervals (depending largely on the overwintering stage), and the same species may experience different conditions and hence emerge at different times in different habitats, most life-cycles end in early, synchronized adult emergence.

Such a pattern of "spring" emergence in some species depends on dormancies that prevent development from being completed during the summer. All individuals, except those that can proceed to emergence immediately after the thaw without further feeding, defer emergence until the following year (Danks and Oliver 1972A, for chironomid midges). Also, many species, emerging with well-developed ovaries, deposit eggs almost at once (Oliver 1968, for *Gynaephora*).

In several kinds of arctic insects, dormancy keeps a fraction of individuals inactive for more than one winter (and the intervening summer(s)) (e.g. Chernov 1978). Such a strategy buffers the population against occasional summers that are unsuitable for development or reproduction, an unpredictability well-known in the Arctic Islands (cf. Danks 1983).

Food Range

Many arctic species are detritivores or predators - trophic groups that tend to contain generalists eating widely available foods. Many arctic herbivores are polyphagous. Such broad food-ranges might be expected where food supplies are limited. However, this generalization is not easy to establish, since many other species (especially herbivores and parasitoids) are specialists, taking into the Arctic the specialist habits typical of their temperate relatives (Danks 1981, 1987). The caterpillar of the butterfly *Rumicia phlaeas* eats *Oxyria* in the Arctic Islands, but elsewhere feeds on *Rumex*, a plant that is absent from the High Arctic. Very few such switches of existing foodplants (correlated with floral changes in the Arctic) are known.

Genetic Adaptations

Parthenogenetic insects are commoner in the Arctic (Table 5) than farther south. Such parthenogenesis has been correlated with the difficulty of mating in harsh conditions. In particular, it has been considered as an adaptation to buffer well-adapted genotypes by minimizing genetic responses to change (Danks 1979; Downes 1965). In unpredictable environments like the Arctic, the rapid elimination of temporarily "unsuitable" genes would usually prove to be disadvantageous.

General Considerations

The characteristic adaptations of arctic insects demonstrate that many species survive in these harsh habitats by avoiding, rather than confronting, the worst conditions. For example, they seek out the most favourable habitats or microsites. The various adaptations of arctic insects, though characteristic, are known also from certain temperate species. They are merely more frequent (e.g. parthenogenesis), more conspicuous (e.g. basking) or better-developed (e.g. hairiness) in the Arctic. Moreover, adaptations may be assembled into complementary sets, such as simultaneous adaptations for overwintering, cold-hardiness and seasonal control of the life-cycle.

One especially interesting discovery, possible only because arthropods are so diverse, is that the ecological pressures of arctic life can be overcome in markedly different ways. Even though long life-cycles, generalist feeding and small size appear to be prevalent in High Arctic arthropods, species with annual life-cycles, specialist herbivores and large insects also occur there. Apparently, such adaptive types depend chiefly on the previous evolutionary history of a given group that may allow appropriate adaptations to be developed. The selective taxonomic composition of the arctic fauna accords with this view.

Many linked or alternative adaptations therefore can meet particular arctic conditions. Studies of adaptation are very difficult, and may lead to spurious conclusions because the adaptive value of a given trait often cannot be directly tested but may be determined only by correlation and the apparent "reasonableness" of the supposed adaptation. Paradoxically, in a few groups, intensive studies in a small area have been carried out in the Arctic in more detail than for comparable temperate situations (e.g. Corbet and Danks 1973). Typically, however, detailed biological information on many more arctic species is required to refine existing generalizations about the range of foods eaten, the prevalence of metabolic adaptations, and the control of emergence and activity by ambient conditions.

ECOLOGICAL RELATIONSHIPS

Habitats

The habits of most arthropods are relatively consistent at the generic and even the family level, so that general habitats can be inferred from the taxonomic composition of the fauna as well as from collecting data. Aquatic habitats contain more arthropods in the Arctic than elsewhere (Figure 4). Indeed, most of the production in arctic terrain comes from fresh waters (Ryan 1977; Welch 1973). Terrestrial forms therefore comprise a smaller fraction of arctic than of other faunas. Terrestrial species that

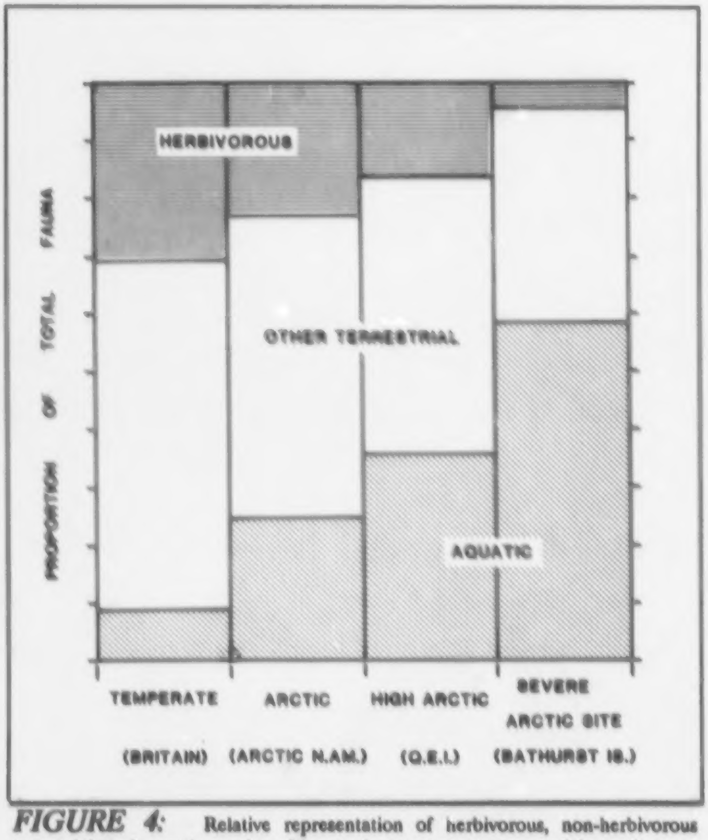


FIGURE 4: Relative representation of herbivorous, non-herbivorous terrestrial, and aquatic species of insects in a temperate area and in arctic areas of different severity (based on named species; data from Danks 1987).

live in or near the soil are relatively well represented, however, especially in moist sites, whereas the number of herbivores is markedly reduced - to a much greater degree than the plants on which they could feed (Danks 1987). Ectoparasites living on vertebrate hosts also are well represented in the Arctic (cf. Phthiraptera, Table 3).

Most of the arctic fauna therefore comes from three types of habitat: (1) shallow waters; and (2) surface soils - both of which are warmed by the sun; and (3) the skin of warm-blooded animals. In the Canadian Arctic Islands, these are the most hospitable habitats available to arthropods.

Trophic Groups

Like ecosystems everywhere, arctic systems are decomposition-based, and saprophagous arthropods (those feeding on decaying matter) are especially significant in the Arctic. Poor drainage above permafrost conserves terrestrial nutrients; locally rich sites are associated with vertebrates (see below); substantial allochthonous ("foreign") detritus enters aquatic habitats. Members of several characteristic families from the Arctic Islands (Table 4) are primarily saprophagous in the broad sense. They eat detritus, algae, bacteria or fungal hyphae in decaying material, for example. Saprophages include the larvae of flies such as tipulids, chironomids, mycetophilids, sciarids and anthomyiids, as well as many springtails and oribatid mites. These groups are the dominant arctic arthropods in soils and fresh waters.

Nevertheless, arthropods belonging to all of the other trophic groups occur in the Arctic. Arthropod predators of other small arthropods are common, especially in the nutrient-rich sites where prey is most abundant. Predators are found in the characteristic families Erigonidae (spiders), Rhagidiidae (mites) and Muscidae (flies), especially in the genus *Spilogona*. Parasitoids of other arthropods are well represented in the Arctic Islands (ichneumonid wasps, other parasitic wasps and tachinid flies). Parasitoids act in many ways like predators because they grow in or on a single host, which eventually is killed and consumed. Arctic parasitoids attack butterflies and moths, sawflies, flower flies, fungus gnats, muscoid flies, and other groups. Reported or potential parasitoids are known from the Arctic Islands for all kinds of insects that commonly occur there.

Ectoparasites of vertebrates are characteristic arctic arthropods. They feed on blood, tissue fluids, or hair. Most species of birds and mammals have at least one or two species each of more or less host-specific lice and fleas, as well as several kinds of mites (Emerson 1972; Holland 1985; Lindquist *et al.* 1979). There are also some less specific ectoparasites.

Phytophagous (plant-eating) forms are present in the Arctic, although rather poorly represented (see above). Their poor representation seems to be due chiefly to general climatic constraints that eliminate species living in less favourable microhabitats, rather than to the absence of food plants or to other particular insect-plant interactions (Danks 1987).

Although the trophic status of many arctic arthropods is known generally, we lack detailed biological information for most species. Whether some saprophages are detritivores or fungivores, for example, is not known. Some crane fly larvae eat living as well as dead plant tissues (Striganova 1982). Moreover, some species commonly associated with sites of decay and assumed to be saprophages may even be predators exploiting locally high populations of other species. By the same token, detailed taxonomic and ecological work is required to understand the ecological significance (as opposed to the basic habits) of most species.

Ecosystem Function

All of the trophic groups known from temperate areas are found in arctic systems; the total fauna, including arthropods, is ecologically as well as taxonomically diverse. Therefore, arctic ecosystems are not the "simple" systems sometimes claimed.

Trophic interactions demonstrate the many interdependencies in arctic ecosystems (Table 6). Various arthropods depend on vertebrates directly as hosts, on their dung or carrion, or live in nests or burrows of vertebrates. Populations of saprophages such as blow flies can depend on the lemming cycle, for example (Chernov 1973). A few species, such as the winter gnat (*Trichocera columbiana*) and perhaps some anthomyiid flies, appear to be obligate lemming associates, since adults have been collected only in or near burrow entrances. Grazing and trampling by vertebrates may alter the suitability of habitats for arthropods. In turn, vertebrates, especially arctic migratory birds, depend heavily on supplies of arthropod food to rear their young.

Some arthropods depend on plants. A characteristic fauna of butterflies and moths, sawflies, aphids, and several other insects consumes plant tissues. A much larger number of insects visits flowers for nectar or pollen. Bumble bees use pollen to rear their brood; large flies such as the muscid (*Pogonomyioides segnis*) eat pollen (McAlpine 1965B). At

TABLE 6 : SUMMARY OF SOME TROPHIC INTERACTIONS BETWEEN ARTHROPODS AND OTHER ORGANISMS[1].

INTERACTION BETWEEN AND	NOTES	EXAMPLES
Arthropods / Vertebrates	Many saprophages depend on dung or carrion	Blow flies, some crane flies, midges, etc.
	Some saprophages scavenge in vertebrate nests or burrows	Some mites, etc.
	Ectoparasites attack birds and mammals	Characteristic biting flies, many ectoparasitic mites, fleas, lice, etc.
Arthropods / Plants	Several arthropod herbivores eat arctic plants	Butterflies, moths, sawflies, aphids, etc.
	Many arctic arthropods visit flowers, for nectar or pollen (and for basking or other activities)	Bumble bees, various flies; mosquitoes, butterflies, etc.
Arthropods / Arthropods	Parasitoids of insects such as sawflies and moths are numerous	Chiefly ichneumonids, but also chalcidoids, braconids, etc.
	Some mites are ectoparasitic on arthropods	Water mites
	A few nest parasites steal nest-provisions or parasitize established nests of related species	The bumble bee (Bombus hyperboreus)
	Many predators attack other arthropods	Diving beetles, several kinds of flies, and other insects. Small predatory mites and spiders are especially numerous
Arthropods / Microflora	Arthropods stimulate decomposition	Many mites, springtails
Vertebrates / Arthropods	Many arctic birds prey on arthropods, especially to feed the young; non-insectivorous adults also supplement their diet with insects	Large or abundant prey are most used (e.g. crane flies, some midges), but also Collembola and other small arthropods
	Mammals and fishes eat insects	
Invertebrates/Arthropods	Invertebrate parasites of arthropods are widely distributed in the Arctic	Microsporidians, mermithids, etc.

---

[1] See references in text and Danks (1981).

Lake Hazen on Ellesmere Island, more than a hundred species of insects are known to visit flowers for nectar (Kevan 1970, 1973). In turn, insects pollinate flowers. Although relatively few arctic plants rely exclusively on insect-pollination, seed set of many species is enhanced thus, and several of the most abundant High Arctic plants (e.g. *Salix arctica*, *Dryas integrifolia* and *Saxifraga oppositifolia*) are chiefly insect-pollinated (Danks 1987; Kevan 1972).

Parasitism and predation among arthropods generate further cross-links in arctic systems. Some predators consume arthropods from different trophic levels, leading to complex food-chains. Moreover, both short food-chains (e.g. plant detritus, to tipulid larvae, to insectivorous birds) and long food-chains (e.g. dead plant material, to fungi, to springtails, to small spiders, to large spiders, to shore birds, to egg predators such as arctic foxes) occur.

Arthropods also interact with the soil microflora in helping to cycle nutrients. Decomposition by the microflora is much faster in the presence of arthropods than in their absence (Douce and Crossley 1982; Whittaker 1974). Preliminary evidence suggests that arthropods stimulate decomposition by comminuting litter into smaller fragments that can be invaded by microflora, inoculating the fragments with microflora, and by grazing microfloral populations to levels of exponential growth (Douce and Webb 1978).

Cross-links in arctic systems also transfer resources from one habitat to another (Table 7). Some of the trophic links that do this, enhanced by the polyphagy of many species, have already been discussed. Larvae from aquatic habitats are transported to terrestrial habitats when they are eaten by birds, or when they move there after emerging as adults. Conversely, some terrestrial insects, especially weakly-flying forms, are washed into aquatic habitats along with terrestrial detritus. Terrestrial groups from lower ground are transported to nest sites by foraging birds. Many soil-dwelling larvae emerge as aerial adults.

Climatic fluctuations, and other factors influenced by them, lead to great variation from year to year in the supply of resources and in the abundance of particular insect species (e.g. Danks 1981, p. 119). Repeated sampling in one place over long intervals to assess such changes would be worthwhile (McAlpine 1965A).

Various processes therefore act together to generate complexity within arctic systems. A partial food-web emphasizing arthropod components (Figure 5) illustrates this complexity.

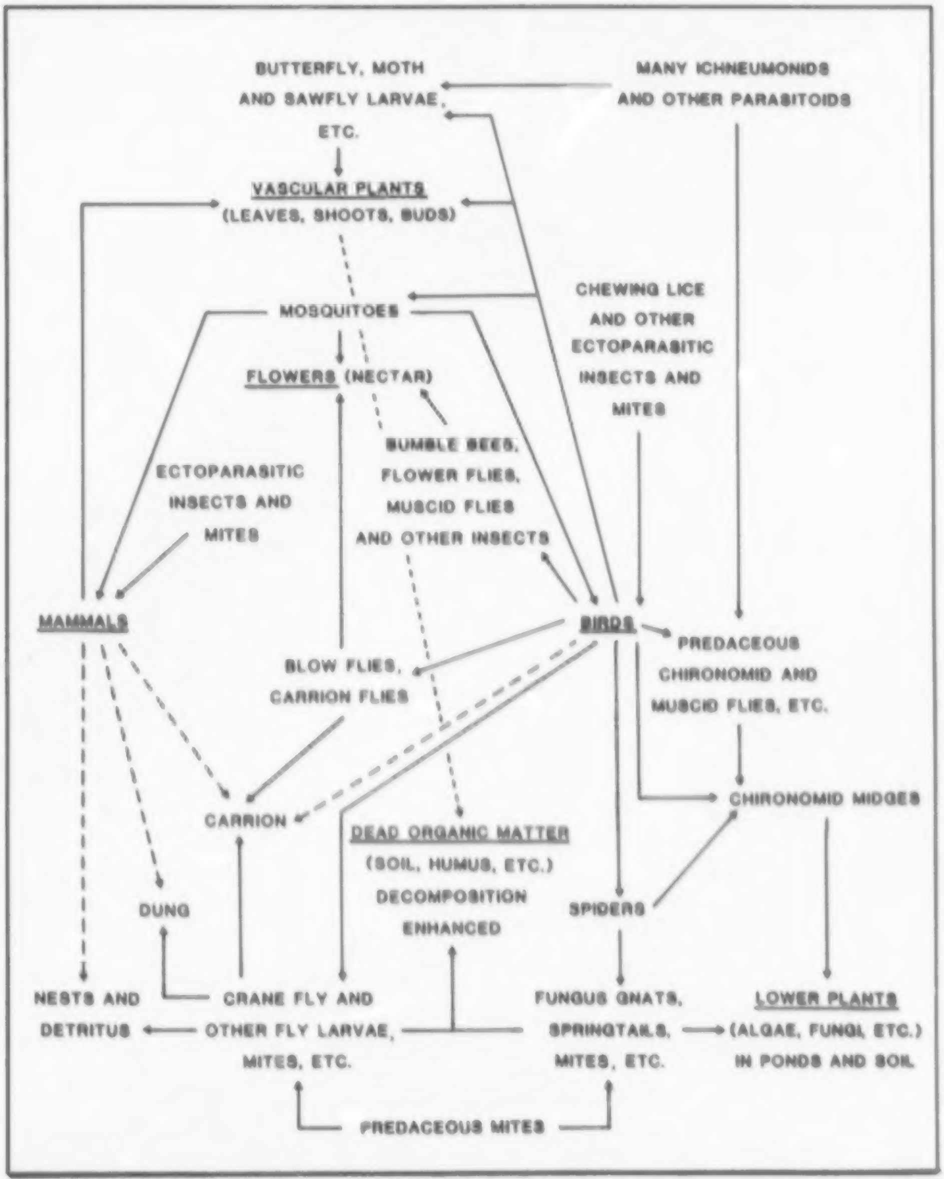

BUTTERFLY, MOTH AND SAWFLY LARVAE, ETC.
MANY ICHNEUMONIDS AND OTHER PARASITOIDS
VASCULAR PLANTS (LEAVES, SHOOTS, BUDS)
CHEWING LICE AND OTHER ECTOPARASITIC INSECTS AND MITES
MOSQUITOES
FLOWERS (NECTAR)
BUMBLE BEES, FLOWER FLIES, MUSCID FLIES AND OTHER INSECTS
ECTOPARASITIC INSECTS AND MITES
MAMMALS
BIRDS
PREDACEOUS CHIRONOMID AND MUSCID FLIES, ETC.
BLOW FLIES, CARRION FLIES
CHIRONOMID MIDGES
CARRION
DEAD ORGANIC MATTER (SOIL, HUMUS, ETC.) DECOMPOSITION ENHANCED
SPIDERS
DUNG
NESTS AND DETRITUS
CRANE FLY AND OTHER FLY LARVAE, MITES, ETC.
FUNGUS GNATS, SPRINGTAILS, MITES, ETC.
LOWER PLANTS (ALGAE, FUNGI, ETC.) IN PONDS AND SOIL
PREDACEOUS MITES

FIGURE 5: Simplified scheme of relationships of arctic arthropod faunas with some of the other biota (interaction except with arthropods, and some links in decomposer food-chains, are omitted for clarity). Solid arrows show trophic dependencies; broken arrows show products of organisms.

TABLE 7: GROUPS THAT TRANSFER RESOURCES BETWEEN HABITATS.

SAMPLE GROUPS	RESOURCES TRANSFERRED FROM	RESOURCES TRANSFERRED TO
Various aquatic groups eaten by birds	Aquatic (and marine and littoral) habitats	Terrestrial habitats
Chironomid midges and other aquatic groups	Aquatic larvae	Terrestrial adults
Predatory fly-larvae (e.g. Spilogona)	Chironomids in aquatic and semi-aquatic substrates	Aerial habitat of Spilogona adults
Many groups	Dead arthropods in terrestrial habitats	Detritus in aquatic habitats, especially at snowmelt
Many groups	Terrestrial habitats	Aquatic habitats (by accident)
Crane flies	Larvae in soil-layers	Adults in aerial zone
Various terrestrial groups eaten, especially by young birds	Arthropod habitats in valleys	Nest sites on ridges
Some vertebrate ectoparasites	Vertebrate blood and tissues	Excrement or eggs in soil and aquatic substrates
Blow flies, etc.	Vertebrate carrion and dung on surface	Aerial adults after development of decomposer larvae
Larvae of butterflies, moths, etc.	Plant leaves, etc.	Leaf fragments and excrement in litter
Many groups	Nectar of flowers	Used for flight by aerial adults
Bumble bees, some other groups	Pollen of flowers	Aerial adults

CONCLUSIONS

Hundreds of arthropod species live in the Canadian Arctic Islands. They are involved in northern ecosystems in the majority of the many ways known for temperate zones. Their general numerical importance makes them significant as decomposers, pollinators, food for birds, etc.

The fauna is much poorer than farther south, but considerable diversity remains. Species that survive on the Arctic Islands do so by means of coincident advantages for life in harsh environments, such as particular habitats, foods, and life-cycles, most of which stem from pre-existing habits of given taxonomic groups. Species that live in surface soil or shallow freshwaters warmed by the sun, or on the skin of warm-blooded animals, are most common. Species that rely on generally available food such as detritus are prevalent. Diverse adaptations to cold and unpredictable climates are best developed in the arctic species, even though they occur in insects from other life zones.

Interactions among arthropods and other arctic organisms are especially noteworthy. The arctic ecosystem is not simple. Diversity is high enough to retain considerable complexity, but complexity that can perhaps be more easily studied because diversity is not overwhelming. However, studies must be based on careful taxonomic and biological work. Most of the conclusions presented in this paper stem from basic collecting and identification of the fauna, because the major clues about habitats and trophic structure were derived from an analysis of faunal composition. Further basic taxonomic work, especially concerning inadequately known groups like the mites and parasitic Hymenoptera, therefore is necessary.

More ecological data on arctic species are also required. For example, generalist feeders appear to be especially common, presumably correlated with shortage of resources. So are denizens of generalized soil microsites. However, such generalists may not be as prevalent as present data suggest, since the detailed habits of many species of the decomposer-complex are unknown. In gathering such data, studies of arctic systems are likely to prove of wide ecological interest.

ACKNOWLEDGEMENTS

I thank Dr. V.M. Behan-Pelletier and Dr. R.A. Ring for helpful comments on the manuscript.

REFERENCES

Addison, J.A. 1975. Ecology of Collembola at a High Arctic site, Devon Island, N.W.T. Ph.D. thesis, University of Calgary, Calgary, Alberta. 212 pp.

______. 1977. Population dynamics and biology of Collembola on Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 363-382.

Babb, T.A. and L.C. Bliss. 1974. Susceptibility to environmental impact in the Queen Elizabeth Islands. Arctic 27(3):234-237 and map.

Block, W. and L. Sømme. 1982. Cold hardiness of terrestrial mites at Signy Island, Maritime Antarctic. Oikos 38(2):157-167.

Böcher, J. 1972. Feeding biology of *Nysius groenlandicus* (Zett.) (Heteroptera:Lygaeidae) in Greenland. Meddelelser om Grønland 191(4):1-41.

Borror, D.J., D.M. DeLong, and C.A. Triplehorn. 1981. An introduction to the study of insects. Fifth Edition. Saunders, Philadelphia, Toronto, etc. 827 pp.

Butler, M.G. 1982. A 7-year life cycle for two *Chironomus* species in arctic Alaskan tundra ponds (Diptera:Chironomidae). Canadian Journal of Zoology 60(1):58-70.

Chernov, Yu. I. 1973. [A review of the trophic groups of invertebrates in typical tundra subzone of western Taimyr.] In: [Biogeocenoses of Taimyr Tundra and Their Productivity, Volume II]. Edited by: B.A. Tikhomirov and N.V. Matveyeva. (In Russian - English translation in International Tundra Biome Translation 12:18-29).

______. 1978. [Adaptive features of the life cycles of tundra zone insects.] Zhurnal Obshchei Biologii 39(3):394-402. (In Russian, English summary).

Corbet, P.S. 1965. Reproduction in mosquitoes of the High Arctic. Proceedings of the 12th International Congress of Entomology (London, 1964):817-818.

______. 1972. The microclimate of arctic plants and animals, on land and in fresh water. Acta Arctica 18:1-43.

Corbet, P.S. and H.V. Danks. 1973. Seasonal emergence and activity of mosquitoes in a High Arctic locality. Canadian Entomologist 105(6):837-872.

______. 1975. Egg-laying habits of mosquitoes in the High Arctic. Mosquito News 35(1):8-14.

Danks, H.V. 1978. Modes of seasonal adaptation in the insects. I. Winter survival. Canadian Entomologist 110(11):1167-1205.

______. (Editor). 1979. Canada and its insect fauna. Memoirs of the Entomological Society of Canada 108:1-573.

______. 1980. Arthropods of Polar Bear Pass, Bathurst Island, Arctic Canada. Syllogeus 25:1-68.

______. 1981. Arctic arthropods. A review of systematics and ecology with particular reference to the North American fauna. Entomological Society of Canada, Ottawa. 608 pp.

______. 1983. Extreme individuals in natural populations. Bulletin of the Entomological Society of America 29(1):41-46.

______. 1987. Insect-plant interactions in arctic regions. Revue d'entomologie du Québec 31(1-2)[1986]:52-75.

Danks, H.V. and D.R. Oliver. 1972A. Seasonal emergence of some High Arctic Chironomidae (Diptera). Canadian Entomologist 104(5):661-686.

______. 1972B. Diel periodicities of emergence of some High Arctic Chironomidae (Diptera). Canadian Entomologist 104(6):903-916.

Douce, G.K. and D.A. Crossley, Jr. 1982. The effect of soil fauna on litter mass loss and nutrient loss dynamics in arctic tundra at Barrow, Alaska. Ecology 63(2):523-537.

Douce, G.K. and D.P. Webb. 1978. Indirect effects of soil invertebrates on litter decomposition: elaboration via analysis of a tundra model. Ecological Modeling 4(4):339-359.

Downes, J.A. 1962. What is an arctic insect? Canadian Entomologist 94(2):143-162.

______. 1965. Adaptations of insects in the Arctic. Annual Review of Entomology 10:257-274.

______. 1969. The swarming and mating flight of Diptera. Annual Review of Entomology 14:271-298.

Emerson, K.C. 1972. Checklist of the Mallophaga of North America (North of Mexico). Desert Test Center, Dugway, Utah; Part I. Suborder Ischnocera. 200 pp.; Part II. Suborder Amblycera, 118 pp.; Part III. Mammal host list, 28 pp.; Part IV. Bird host list, 216 pp.

Fjellberg, A. 1986. Collembola of the Canadian High Arctic. Review and additional records. Canadian Journal of Zoology 64(10):2386-2390.

Fox, A.D. and D.A. Stroud. 1986. Diurnal rhythms in a snow-surface springtail (*Isotoma violacea*, Collembola) and its predators in Equalungmuit Nunaat, West Greenland. Pedobiologia 29(6):405-412.

Haufe, W.O. and L. Burgess. 1956. Development of *Aedes* (Diptera:Culicidae) at Fort Churchill, Manitoba, and prediction of dates of emergence. Ecology 37(3):500-519.

Holland, G.P. 1985. The fleas of Canada, Alaska and Greenland (Siphonaptera). Memoirs of the Entomological Society of Canada 130:1-631.

Kevan, P.G. 1970. High Arctic insect-flower relations; the interrelationships of Arthropoda and flowers at Lake Hazen, Ellesmere Island, N.W.T., Canada. Ph.D. thesis, University of Alberta, Edmonton, Alberta. 399 pp.

______. 1972. Insect pollination of High Arctic flowers. Journal of Ecology 60(3):831-847.

______. 1973. Flowers, insects, and pollination ecology in the Canadian High Arctic. Polar Record 16(104):667-674.

Kevan, P.G., T.S. Jensen, and J.D. Shorthouse. 1982. Body temperatures and behavioral thermoregulation of High Arctic woolly-bear caterpillars and pupae (*Gynaephora rossii*, Lymantriidae:Lepidoptera) and the importance of sunshine. Arctic and Alpine Research 14(2):125-136.

Kevan, P.G. and J.D. Shorthouse. 1970. Behavioural thermoregulation by High Arctic butterflies. Arctic 23(4):268-279.

Kingsolver, J.G. 1985. Butterfly thermoregulation: organismic mechanisms and population consequences. Journal of Research on the Lepidoptera 24(1):1-20.

Kukal, O. and P.G. Kevan. 1987. The influence of parasitism on the life history of a High Arctic insect, *Gynaephora groenlandica* (Wocke) (Lepidoptera:Lymantriidae). Canadian Journal of Zoology 65(1):156-163.

Lantsov, V.I. 1982. [Adaptive characteristics of the life cycle of the arctic crane fly *Tipula carinifrons* (Diptera:Tipulidae).] Ekologiya 13(1):71-76. (Translation in Soviet Journal of Ecology 13(1):67-71).

Leech, R.E. 1966. The spiders (Araneida) of Hazen Camp 81°49'N, 71°18'W. Quaestiones Entomologicae 2(2):153-212.

Lindquist, E.E., B.D. Ainscough, F.V. Clulow, R.C. Funk, V.G. Marshall, H.H.J. Nesbitt, B.M. O'Connor, I.M. Smith, and P.R. Wilkinson. 1979. Acari. In: Canada and Its Insect Fauna. Edited by: H.V.Danks. Memoirs of the Entomological Society of Canada 108:252-290.

MacLean, S.F., Jr. 1983. Life cycles and the distribution of psyllids (Homoptera) in arctic and subarctic Alaska. Oikos 40(3):445-451.

McAlpine, J.F. 1965A. Insects and related terrestrial invertebrates of Ellef Ringnes Island. Arctic 18(2):73-103.

______. 1965B. Observations on anthophilous Diptera at Lake Hazen, Ellesmere Island. Canadian Field-Naturalist 79(4):247-252.

Oliver, D.R. 1968. Insects. In: Science, History and Hudson Bay, Volume I. Edited by: C.S. Beals and D.A. Shenstone. Energy, Mines and Resources Canada, Ottawa. pp. 416-436.

______. 1984. Male dimorphism in an arctic chironomid. Memoirs of the American Entomological Society 34:235-240.

Richards, K.W. 1973. Biology of *Bombus polaris* Curtis and *B. hyperboreus* Schonherr at Lake Hazen, Northwest Territories (Hymenoptera:Bombini). Quaestiones Entomologicae 9(2):115-157.

Richards, W.R. 1963. The Aphididae of the Canadian Arctic (Homoptera). Canadian Entomologist 95(5):449-464.

Ring, R.A. 1981. The physiology and biochemistry of cold tolerance in arctic insects. Journal of Thermal Biology 6:219-229.

______. 1983. Cold tolerance in Canadian arctic insects. In: Plant, Animal and Microbial Adaptations to Terrestrial Environments. Edited by: N.S. Margaris, M. Arianoutsou-Faraggitaki, and R.J. Reiter. Plenum Press, New York. pp. 17-29.

Roland, J. 1982. Melanism and diel activity of alpine *Colias* (Lepidoptera, Pieridae). Oecologia (Berlin) 53(2):214-221.

Ryan, J.K. 1977. Synthesis of energy flows and population dynamics of Truelove Lowland invertebrates. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 325-346.

Ryan, J.K. and C.R. Hergert. 1977. Energy budget for *Gynaephora groenlandica* (Homeyer) and *G. rossii* (Curtis) (Lepidoptera:Lymantriidae) on Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 395-409.

Scholander, P.F., W. Flagg, V. Walters, and L. Irving. 1953. Climatic adaptation in arctic and tropical poikilotherms. Physiological Zoology 26(1):67-92.

Sherman, P.W. and W.B. Watt. 1973. The thermal ecology of some *Colias* butterfly larvae. Journal of Comparative Physiology 83(1):25-40.

Sømme, L. 1981. Cold tolerance of alpine, arctic, and antarctic Collembola and mites. Cryobiology 18:212-220.

Striganova, B.R. 1982. [Food relationships of soil larvae of crane flies (Diptera, Tipulidae) in the arctic tundra.] Zoologicheskii Zhurnal 61(4):535-542. (In Russian, English summary).

Stubbs, A.E. 1982. Conservation and the future for the field entomologist. Proceedings and Transactions of the British Entomological and Natural History Society 15(3-4):55-67.

Vockeroth, J.R. 1972. A new nearctic genus of Mycetophilidae (Diptera) with a stenopterous female. Canadian Entomologist 104(10):1529-1533.

Welch, H.E. 1973. Emergence of Chironomidae (Diptera) from Char Lake, Resolute, Northwest Territories. Canadian Journal of Zoology 51(11):1113-1123.

Whittaker, J.B. 1974. Interactions between fauna and microflora at tundra sites. In: Soil Organisms and Decomposition in Tundra. Edited by: A.J. Holding, O.W. Heal, S.F. MacLean, Jr, and P.W. Flanagan. Tundra Biome Steering Committee, Stockholm. pp. 183-196.

Y6
Y - R
Eureka Aug 17

Illustrated by Brenda Carter

CRANE FLIES (DIPTERA:TIPULIDAE) OF THE ARCTIC ISLANDS

Fenja Brodo[1]

Abstract: Sixteen species of Tipulidae occur on the Canadian Arctic Islands. They are a distinct Arctic element; their combined, known distributions are restricted to Arctic, Boreal and Alpine regions in North America. The largest populations and greatest concentration of species is in the Low Arctic. Seven species are known from the High Arctic, and the distributions of six of these extend to Ellesmere Island. The High Arctic species tend to be more common with the broadest distributions. At least four of the High Arctic species are circumpolar.

As with most other insects, there is an inverse correlation with species richness and latitude. However, the proportion of Tipulidae with respect to the entire insect fauna remains roughly the same.

Arctic Island Tipulidae may have evolved during the Pleistocene and possibly in high-altitude wetlands south of the ice sheets, as well as in several of various refugia postulated.

Résumé: On trouve seize espèces de Tipulidés sur les îles de l'Arctique canadien. Elles constituent [illegible]ent distinct de l'Arctique, et leurs distributions connues combinées sont limitées aux régions arctique, boréale et alpine d[illegible]rique du Nord. Les plus vastes populations et les plus grandes concentrations d'espèces se retrouvent dans le Bas-Arctique. [illegible] en connaît sept espèces dans le Haut-Arctique et la distribution de six d'entre elles s'étend jusqu'à l'île Ellesmere. Les espèces du Haut-Arctique tendent à être plus connues, et avoir les plus larges distributions. Au moins quatre espèces du Haut-Arctique sont présentes tout le tour du pôle.

Comme dans le cas de la plupart des insectes, il y a une relation inverse entre la richesse en espèces et la latitude. Cependant, la proportion de Tipulidés dans toute la faune entomologique reste sensiblement la même.

Les Tipulidés des îles de l'Arctique peuvent avoir évolué pendant le Pléistocène et, peut-être, dans les terres humides en altitude au sud des nappes de glace, de même que dans plusieurs des divers refuges naturels envisagés.

INTRODUCTION

Crane flies are a more important and more conspicuous faunal element as one goes northward. The number of crane fly species, indeed of most insects, declines rapidly with increasing latitude, but this phenomenon is offset in the crane flies by the enormous populations attained by several species. The sudden appearance of large numbers of tipulids is a characteristic of the Arctic (Chernov 1985; Holmes 1966; MacLean 1975). Yet possibly because these flies are not particularly beautiful and pose no threat to humanity, their biology, species-composition and distribution are poorly known (Teskey 1979, p. 396).

An interest in the Tipulidae and the presence of over 2,000 unsorted Arctic Tipulidae in the Canadian National Collection (CNC) prompted this study. My purpose was to determine which species of crane flies occur in the Canadian Arctic Islands, and to assess their distributions and morphological and geographical affinities. I was also interested in determining the thoroughness and extent of the collecting records with a view to suggesting where further collecting might be profitable.

---

[1] Research Associate, National Museum of Natural Sciences, Ottawa, Ontario K1P 6P4

SPECIES COMPOSITION AND DISTRIBUTION

Sixteen species of Tipulidae are listed from the Canadian Arctic Islands (Table 1). Although this represents an addition of only two species, we now have a far better understanding of the distributions of these species. Previous to this study and that of *Prionocera* (Brodo 1987), collections from only seven Arctic Island localities had been recorded: Clyde, Baffin Island (Alexander 1947); Nettilling Lake, Baffin Island (McDunnough 1929); Cornwallis Island (Bruggemann 1958); Ellesmere Island (Lake Hazen) (Bruggemann 1958; Oliver 1963); Melville Island (Winter Harbour) (Kirby 1824); Prince Patrick Island (Mould Bay) (Bruggemann 1958); and Southampton Island (Alexander 1934). By contrast, information from over 40 Arctic Island localities is included in this study, as well as additional collection data and literature records from mainland northern Canada, Alaska and Greenland.

The combined, known distributions of the 16 species of the Arctic Archipelago are shown in Figure 1. These species form a distinctly northern element. They are almost exclusively restricted to the Arctic and Boreal regions, except for one species discussed below. None of these species can be considered rare, and many are common and widespread in the Arctic. By contrast, I have recorded several species on the basis

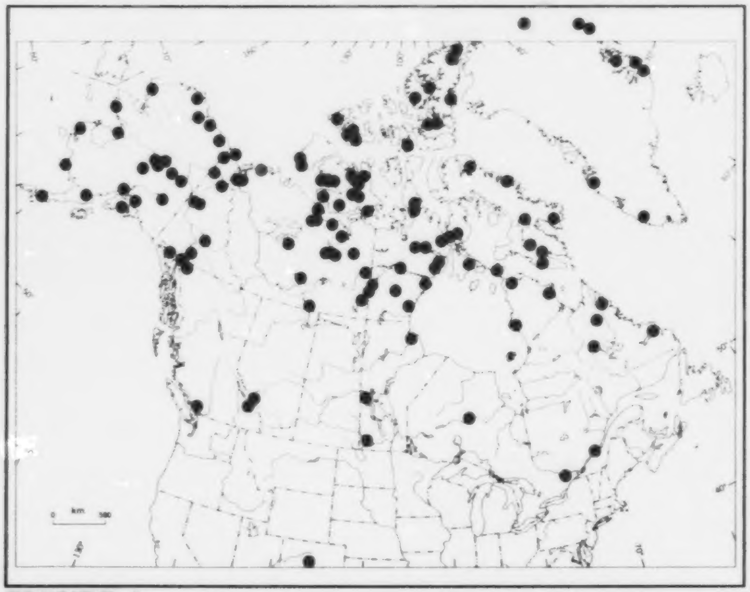


FIGURE 1: **Combined distribution records of the 16 Tipulidae species recorded from the Canadian Arctic Archipelago.**

TABLE 1: KNOWN RANGES OF CRANE FLIES OF THE CANADIAN ARCTIC ISLANDS.

SPECIES	ECOSYSTEMS							NEARCTIC			PALEARCTIC	
	Temperate	Alpine	Boreal Forest	Boreal Forest-Tundra	Low Arctic	Mid Arctic	High Arctic	West of Hudson Bay	East	Greenland	West of Urals	East
Erioptera (Symplecta) hybrida complex	x		x	x	x		x	x	x		x	
Erioptera (Symplecta) sp.					x			x				
Dactylolabis rhicnoptiloides (Alexander)				x	x	x	x	x	x			
Nephrotoma lundbecki (Nielsen)		x	x	x	x	x	x	x	x	x	x	x
Prionocera ominosa (Alexander)				x	x	x		x	x			x
Prionocera recta Tjeder		x		x	x	x		x	x		x	x
Prionocera ringdahli Tjeder		x			x	x		x	x		x	x
Tipula (Angarotipula) parrioides (Alexander)[1,2]			x	x	x	x		x	x		x?	x?
Tipula (Arctotipula) besselsi Osten Sacken		x	x	x	x	x	x	x		x	x	x
Tipula (Arctotipula) suttoni Alexander					x	x		x	x			
Tipula (Arctotipula) thulensis Alexander[1]		x			x	x	x	x	x			
Tipula (Arctotipula) tribulator Alexander[1]			x		x	x		x	x			
Tipula (Pterelachisus) diflava Alexander					x	x		x				
Tipula (Pterelachisus) hewitti Alexander[3]		x	x	x	x	x	x	x	x			
Tipula (Pterelachisus) hollandi Alexander					x	x		x	x			
Tipula (Vestiplex) arctica Curtis		x	x	x	x	x	x	x	x	x	x	x

---

[1] New records for the Canadian Arctic Islands.

[2] May include the Palearctic species *tumidicornis* Lundström.

[3] Includes *Tipula macleani* Alexander.

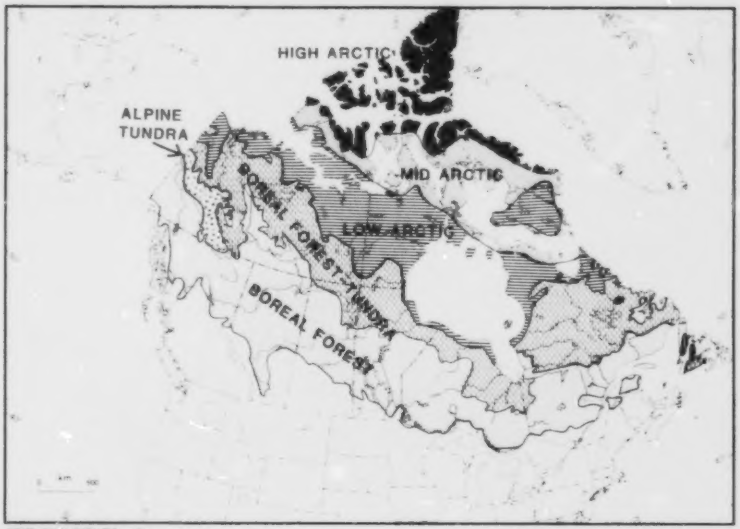

HIGH ARCTIC
ALPINE TUNDRA
MID ARCTIC
LOW ARCTIC
BOREAL FOREST-TUNDRA
BOREAL FOREST

FIGURE 2: Major ecosystems in northern Canada (after Edlund 1984).

of only one or two specimens and from only one locality in the western Alpine Tundra and Boreal Forest-Tundra Regions. The larger collections and localities exhibiting greatest species diversity are in the Mid and Low Arctic (Figure 2). Indeed, all 16 species occur in the Low Arctic, and species diversity drops off rapidly northward. About 50 Tipulidae occur in Boreal and Arctic North America (Danks 1981), but my data indicate that most of these do not extend into the Arctic Islands.

Chernov (1985) suggests that circumboreal species tend to lack close relatives. Probably eight of the Arctic Island species are circumboreal (Table 1). The taxonomic status of two species is still in doubt. Circumboreal *Tipula (Arctotipula) besselsi* has close relatives (see below). The three *Prionocera* species have sister species (Brodo 1987). *Nephrotoma lundbecki*, although placed in the *lundbecki* subgroup, does not seem to have a sister species (Oosterbroek 1980, 1984). The taxonomic relationships of the other species have yet to be decided.

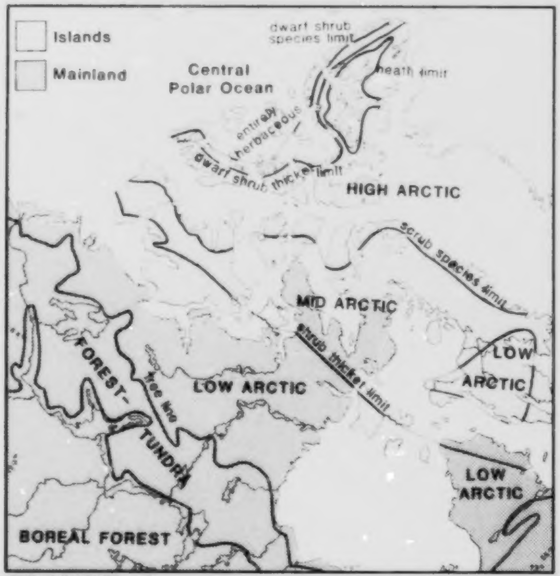

Islands
Mainland
Central Polar Ocean
dwarf shrub species limit
heath limit
entirely herbaceous
dwarf shrub thicket limit
HIGH ARCTIC
scrub species limit
MID ARCTIC
shrub thicket limit
LOW ARCTIC
FOREST-TUNDRA
tree line
LOW ARCTIC
LOW ARCTIC
BOREAL FOREST

FIGURE 3: Major vegetative zones in the Arctic (modified from Edlund 1986).

Circumpolarity may be a consequence of out-competing sister species. The presence of circumpolar arctic species having closely related sister species may reflect the youthfulness of the ecosystem. Little is known of competition and resource partitioning among these species.

The distributional pattern of crane flies on the Arctic Islands is not immediately evident. These flies occur near the northernmost limits of land (Alert, Ellesmere Island), and seem to have invaded most of the islands. However, comparison of Figure 1 with Figure 3 reveals that the "dwarf-shrub species limit" is also a crane fly limit. No tipulids have been found in the entirely herbaceous zone (McAlpine 1964, 1965). As Edlund and Alt (1989) point out, this region experiences the harshest climate in the North. Minimum summer temperatures, heavy cloud-cover and shortest melt-season occur here. Thus the sharply reduced growing season, the scarcity of available water and poorly-developed soils apparently preclude crane fly development. Absence of crane flies is probably not a collecting omission, nor does it reflect lack of time available for invasion of this region.

Similarly, crane flies have not been reported from Bathurst Island despite entomological investigations (Danks and Byers 1972; Bissett 1977; Danks 1980). I have seen no tipulid records from Devon, Prince of Wales and Somerset islands or the long southwestern flank of Baffin Island. Lack of adequate collecting may be the problem. The scattered distributions of suitable habitats (Bruggemann 1958; Danks 1981; Edlund 1983A,B), very short periods of adult emergence and dramatic annual climatic differences (Danks 1981) suggest that many visits over several years are necessary to establish adequate faunal records in the High Arctic. This means that no Arctic Island locality can be considered to have been adequately collected with respect to its crane fly fauna.

ELLESMERE AND AXEL HEIBERG ISLANDS

Six species are known from Ellesmere and Axel Heiberg islands: *Erioptera (Symplecta) hybrida cana* complex, *Erioptera (Symplecta)* sp., *Dactylolabis rhicnoptiloides*, *Nephrotoma lundbecki*, *Tipula (Arctotipula) besselsi* and *Tipula (Vestiplex) arctica*. A seventh species, *Tipula hewitti*, occurs on northern Baffin Island, and Melville Island in the High Arctic. *Ormosia* sp. was recorded from Lake Hazen, Ellesmere Island (Oliver 1963). I could not locate the specimen and this genus is otherwise not known to occur in the islands.

The climate where these flies were collected is not so severe as the latitude would indicate. Collection sites were in a valley sheltered by an ice-capped mountain chain from the brunt of cold winds off the Central Arctic Ocean to the west. These mountains also act as a barrier to heavy cloud cover from the ocean, thus adding to the "Chinook" or "Foehn"-effect, which lowers the water-vapour content of the air on the leeward side of the mountains. The winter accumulation of snow provides a ready reservoir of water, enhanced by early snow-melt. The albedo effect (reflected solar radiation) is thus minimized (Edlund and Alt 1989). This region has one of the richest floras in the Queen Elizabeth Islands, including diverse wetlands, the domain of several crane flies.

Two species of *Erioptera (Symplecta)* occur on Ellesmere Island. One is apparently a new species and is known only from this locality. The other belongs to a widespread circumpolar complex. The distinctions between the largely Palearctic *hybrida hybrida* complex and the mainly temperate Nearctic *hybrida cana* Walker (Alexander 1955; Theowald 1971) are not clear in the Arctic Island specimens.

ORIGIN AND GEOGRAPHIC AFFINITIES

Most of the Canadian Arctic Islands have been subject to Pleistocene glaciations (Danks 1981), and colonization by plants and animals is relatively recent. The origin and geographic affinities of the Arctic Island species is, therefore, of great interest. As noted above, 15 of the Arctic Island Tipulidae are restricted to the Arctic and Boreal zones, and presumably to the wetter soils therein. Most of these species probably originated before the terrain they now inhabit became available. Presumably they survived the glaciations in one or more of the Arctic Refugia postulated (Danks 1981).

The parallels between Alpine and Arctic tundra forms have long been recognized (Danks 1981). A significant proportion of present arctic taxa may have evolved in alpine conditions (Chernov 1985). Seven of the Arctic Island Tipulidae also occur in Alpine zones (Table 1). *Tipula (V.) arctica* Curtis has been collected in the southern Rocky Mountains, Colorado. *Tipula sacra* Alexander (which I suggest is the sister species to the *besselsi* group discussed below) is known only from the Canadian Rocky Mountains and their foothills.

When the sister-group relationships of the other components of the Arctic Island fauna have been worked out, it is predicted that several other species will show an alpine connection.

TIPULA (ARCTOTIPULA) BESSELSI SPECIES-GROUP

A striking feature of Arctic Tipulidae is the remarkable morphological similarity and broadly overlapping ranges among certain species-groups, making identification difficult. Examples are within the genus *Prionocera* (Brodo 1987), the *Erioptera (Symplecta) hybrida* group, and the *Tipula (Arctotipula) besselsi* group. This contradicts Chernov's (1985) finding that the more closely related the species the more distinct and better differentiated are their ranges.

The *Tipula besselsi* group in North America comprises *besselsi* Osten Sacken, *suttoni* Alexander and *tribulator* Alexander. Apparently only *besselsi* is Holarctic; it seems to be just as closely related to at least two species restricted to the Palearctic (Savchenko 1961). *Tipula besselsi* is also the most widespread of the three species in the Nearctic (Figure 4).

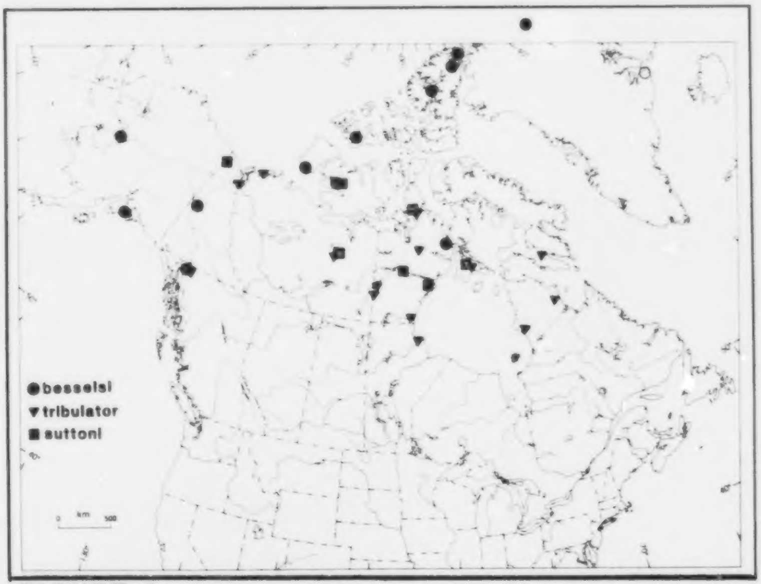


FIGURE 4: Distribution records of species in the *Tipula* (*Arctotipula*) *besselsi* group in North America. Each symbol represents one or more records at that locality.

Usually male crane flies are easier to identify to species than are females. In the *besselsi* group the reverse is true. Females can be distinguished by the shape of a lateral lobe on the terminalia which is usually visible in pinned specimens. On the other hand, the characters that separate the males are often obscured on pinned specimens, making literature references to these species suspect.

The distributions of the three species in North America, based on identifications of several hundred specimens in the CNC, are presented (Figure 4). The range-overlaps suggest that these are indeed well-defined species. Furthermore, the striking morphological similarities noted in the *besselsi* group, in the species of the genus *Prionocera*, and in the species in the *Erioptera (Symplecta) hybrida* complex, suggests that within all these species-groups, evolution has occurred relatively recently. Recent differentiation within these species-groups is also suggested by the extraordinary (for Tipulidae, Byers 1961) record of presumably mismatched attempted matings and the hybrid specimen noted in *Prionocera* (Brodo 1987).

The present overlapping ranges of the species within each group probably reflects the shifting ice fronts of the past. Earlier ranges must have been disrupted several times, and possibly some species were eliminated. To what extent current distributional patterns reflect the climate and each species' ability to recolonize ice-free areas is unknown.

Edlund (1984) shows "... that most [High Arctic] vegetation and plant communities are regionally replicated wherever climatic, soil and moisture conditions are the same, ..." and that these communities are not "... merely heterogeneous groups of pioneer species". The distribution of arctic crane flies may be similarly firmly established, but it is also possible that some of these tipulids may be actively extending or reducing their ranges. There is probably a time-lag between the establishment of the plant community and that of the potential fauna.

PROPORTION OF INSECT FAUNA

Table 2 shows the numbers of species of Tipulidae as a percentage of the entire insect fauna of the region in question. Unlike many other families of insects, the proportionate number of species of Tipulidae increases very slightly with latitude. Tipulids comprise a slightly larger percentage of the estimated insect fauna in the Arctic and on the Arctic Islands than in the temperate zone.

In the North, the Tipulidae make up in quantity for their decrease in variety. Where crane flies occur on the Arctic Islands, they usually hatch abruptly and in very large

TABLE 2: COMPARISON OF ESTIMATED NUMBERS OF SPECIES IN THE TOTAL INSECT FAUNA WITH ESTIMATED NUMBERS OF TIPULID SPECIES.

FAUNAS	CANADA	ARCTIC	CANADIAN ARCTIC ISLANDS	QUEEN ELIZABETH ISLANDS
Total Insect Fauna	66,498[1]	1,805[2]	588[3]	363[3]
Tipulidae	670[1]	50[2]	16	7
Tipulidae/Insect Fauna x 100	1.01%	2.77%	2.72%	1.93%

[1] Danks (1979).
[2] Danks (1981).
[3] Danks (personal communication).

numbers. The shorter, sparser arctic vegetation and the dearth of several other insect groups contribute to their conspicuousness.

ARCTIC ADAPTATIONS

Probably the most important arctic adaptation is the ability of larvae to prolong their life-cycle and develop over several years (MacLean 1973). Thus, they are not decimated by lack of sufficient growing-days in any one year. However, they are vulnerable to predators over a longer period of time. The shortness of summer rather than low temperatures is probably the limiting factor (Pritchard 1983).

Arctic Island Tipulidae tend to be darker and hairier than temperate species. In agreement with Allen's Rule in mammals, the most northern *Prionocera* and *Tipula (Arctotipula)* species have the nasus (small snout at the end of the rostrum; Figure 5) much reduced or absent, and relatively shorter, stouter legs.

Several northern tipulids are noted for wing reduction either in both sexes or only in the female (Downes 1965; Byers 1969). None of the species found on the Arctic Islands has this characteristic. Byers (1969) shows that wing reduction is correlated with adult emergence in a cold environment. One would expect, then, to find brachypterous tipulids on the Arctic Islands: their absence is surprising.

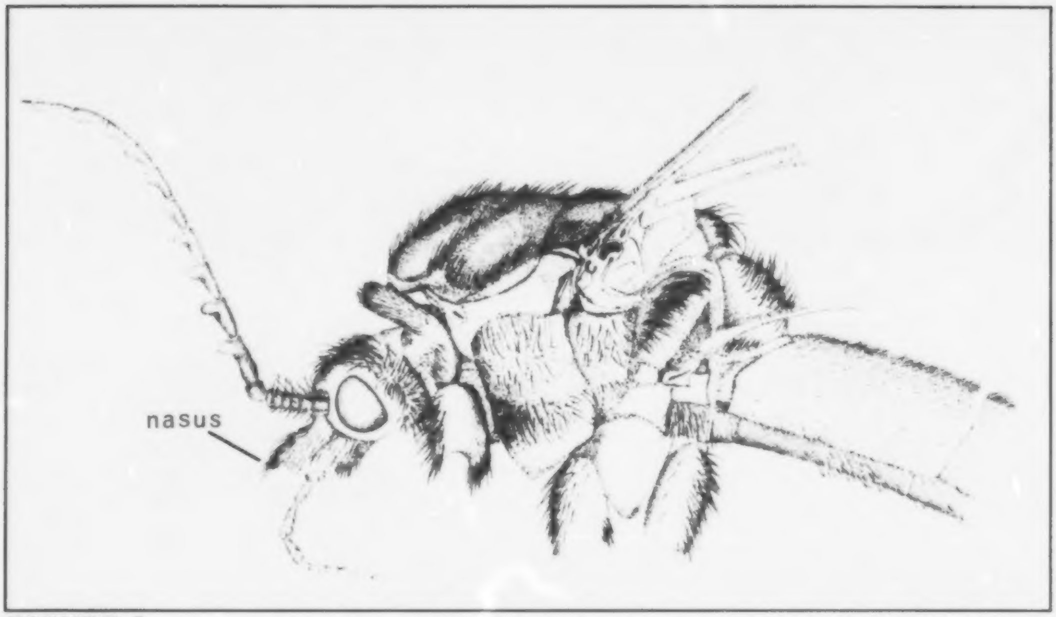


FIGURE 5: A crane fly (Prionocera recta Tjeder, left side view of anterior parts) found in Canadian Arctic Islands, showing the position of the nasus.

Brachypterous crane flies are probably older than the Pleistocene and, I suggest, evolved at high altitudes, not necessarily at high latitudes. Only the more mobile-winged species have been able to colonize the Arctic Islands.

BIOLOGY AND ECOLOGY

Very little is known of the biological or ecological adaptations of Arctic Island Tipulidae. Studies in Alaska and in Siberia give some clues. These northern tipulids seem to be restricted to wet or moist regions , and the larva is the overwintering stage (Chernov 1985). Most northern crane fly larvae are presumed to be herbivores or saprovores, eating living and decaying plants, mostly sedges, grasses and mosses and the rich algal slime surrounding these plants and covering inorganic substrates (Chernov 1985). Preliminary study of the larvae of *Prionocera* (Brodo 1987) indicates that they have a typical vegetarian-type of caeca, although they have been known to eat tabanid larvae (personal communication , H . J . Teskey). The occasional small worm or other invertebrate probably gets eaten , but apparently accidentally. No truly predatory crane flies have been recorded from the Arctic

Islands, although one such species, *Pedicia hannai antennata* occurs at Point Barrow, Alaska (MacLean 1975). Cold-hardiness in Arctic crane flies has not been studied (Pritchard 1983).

PREDATORS

Fourth-instar tipulid larvae are among the larger invertebrates in the Arctic, and several generations of larvae may coexist because of the prolonged life-cycle. Thus populations of several hundred larvae per square metre have been recorded in the tundra of Alaska and Siberia (MacLean 1975; Lantzov 1984; Chernov 1985). The nesting success of shore birds (e.g. sandpipers, plovers, phalaropes) seems to be linked to this crane fly population. Adult birds eat both crane fly larvae and adults (Holmes and Pitelka 1968; personal communication, G.W. Byers). Egg-laying by these birds is abruptly terminated in early summer just when the availability of adult crane flies is rapidly increasing. The hatching of young chicks is apparently timed to correspond to the maximum abundance of adult insects (Holmes 1966).

Adult crane flies are also eaten by Long-tailed Jaegers, several of the smaller arctic gulls, as well as arctic foxes (Chernov 1985).

The highly synchronous adult hatch noted by many workers in the North is apparently correlated with a minimum threshold temperature of 5°C (Clement in Pritchard 1983). Ironically, this results in a higher biomass in harsher climates because last-instar larvae and pupae of several generations accumulate in the substrate until the favourable temperature is reached. This probably has a predator-swamping effect (MacLean and Pitelka 1971).

CONCLUSIONS

The sixteen tipulid species occurring on the Arctic Islands have broad distributions that probably parallel the development of appropriate soils on the islands. Other than tending to be darker and possibly stouter than their more southern relatives, these species do not have striking morphological adaptations. Their ability to survive in the North is more probably related to a flexible life-cycle, which allows for several years of interrupted larval development, and relatively unspecialized feeding requirements.

Little is known of the biology, ecology and competitive interactions among these species.

ACKNOWLEDGEMENTS

This study was greatly facilitated by the generosity of Dr. George W. Byers, University of Kansas, who provided me with his drawings of several important types. I thank Drs. H.J. Teskey and Jeffrey Cumming, Agriculture Canada, for access to the Canadian National Collection, and the National Museum of Natural Sciences for ample work space.

REFERENCES

Alexander, C.P. 1934. II. Diptera collected on Southampton Island by G.M. Sutton. Trichoceridae and Tipulidae. In: G.M. Sutton. The Exploration of Southampton Island, Hudson Bay. Memoirs of the Carnegie Museum 12, Pt 2, Sect. 4:3-10.

______. 1947. Undescribed species of crane-flies from the eastern United States and Canada (Diptera:Tipulidae), Part X (1946). Entomological News 58:245-252.

______. 1955. The crane flies of Alaska and the Canadian Northwest (Tipulidae, Diptera). The genus *Erioptera* Meigen. University of Michigan, Museum of Zoology, Miscellaneous Publications 90:1-33.

Bissett, J. 1977. Preliminary observations on the vascular plants, fungi and insects of Polar Bear Pass, Bathurst Island, N.W.T. 39 pp. (Unpublished report submitted to National Museum of Natural Sciences, Ottawa).

Brodo, F. 1987. A revision of the genus *Prionocera* (Diptera:Tipulidae). Evolutionary Monographs 8:1-93.

Bruggemann, P.F. 1958. Insects and environments of the High Arctic. Proceedings 10th International Congress of Entomology (Montreal, 1956) 1:695-702.

Byers, G.W. 1961. The crane fly genus *Dolichopeza* in North America. University of Kansas Science Bulletin 42(6):665-924.

Byers, G.W. 1969. Evolution of wing reduction in crane flies (Diptera:Tipulidae). Evolution 23(2):346-354.

Chernov, Y.I. 1985. The living tundra. Cambridge University Press, Cambridge. 213 pp. (Translated from Russian by D. Löve).

Danks, H.V. 1980. Arthropods of Polar Bear Pass, Bathurst Island, Arctic Canada. Syllogeus 25:1-69.

______. 1981. Arctic arthropods. A review of systematics and ecology with particular reference to the North American fauna. Entomological Society of Canada, Ottawa. 608 pp.

Danks, H.V. and J.R. Byers. 1972. Insects and arachnids of Bathurst Island, Canadian Arctic Archipelago. Canadian Entomologist 104:81-88.

Downes, J.A. 1965. Adaptations of insects in the Arctic. Annual Review of Entomology 10:257-274.

Edlund, S.A. 1983A. Bioclimatic zonation in a High Arctic region: central Queen Elizabeth Islands. Geological Survey of Canada, Paper 83-1A:381-390.

______. 1983B. Reconnaissance vegetation studies on western Victoria Island, Canadian Arctic Archipelago. Geological Survey of Canada, Paper 83-1B:75-81.

______. 1984. High Arctic plants: new limits emerge. Geos 13(1):10-13.

______. 1986. Vegetation-geology-climate relationships of western Melville Island, District of Franklin. Geological Survey of Canada, Paper 86-1A:719-726.

Edlund, S.A. and B.T. Alt. 1989. Regional congruence of vegetation and summer climate patterns in the Queen Elizabeth Islands, Northwest Territories, Canada. Arctic 42(1):3-23.

Holmes, R.T. 1966. Feeding ecology of the Red-backed Sandpiper (*Calidris alpina*) in Arctic Alaska. Ecology 47:32-45.

Holmes, R.G. and F.A. Pitelka. 1968. Food overlap among coexisting sandpipers on northern Alaskan tundra. Systematic Zoology 17:305-318.

Kirby, W. 1824. Land invertebrate animals. In: Supplement to the Appendix of Captain Parry's Voyage for the Discovery of a North-West Passage, in the years 1819-1820, Containing an Account of the Subjects of Natural History. Appendix X. Natural History. Murray, London. pp. ccxiv-ccxix.

Lantsov, V.I. 1984. Ecology, morphology and taxonomy of arctic crane-flies of the genus *Prionocera* (Diptera:Tipulidae). Zoologischeskii Zhurnal 43(8):1196-1204. (In Russian).

MacLean, S.F., Jr. 1973. Life cycle and growth energetics of the arctic crane fly *Pedicia hannai antenata*. Oikos 24:436-443.

MacLean, S.F., Jr. 1975. Ecology of tundra invertebrates at Prudhoe Bay, Alaska. In: Ecological Investigations of the Tundra Biome in the Prudhoe Bay Region, Alaska. Edited by: J. Brown. Biological Papers, University of Alaska, Special Report No. 2:115-123.

MacLean, S.F., Jr. and F.A. Pitelka. 1971. Seasonal patterns of abundance of tundra arthropods near Barrow. Arctic 24:19-40.

McAlpine, J.F. 1964. Arthropods of the bleakest barren lands: composition and distribution of the arthropod fauna of the northwestern Queen Elizabeth Islands. Canadian Entomologist 96(1-2):127-129.

______. 1965. Insects and related terrestrial invertebrates of Ellef Ringnes Island. Arctic 18(2):73-103.

McDunnough, J.H. 1929. Insects from Baffin Island. In: J.D. Soper - A faunal investigation of Southern Baffin Island. National Museum of Canada, Bulletin 53:118-119.

Oliver, D.R. 1963. Entomological studies in the Lake Hazen area, Ellesmere Island, including lists of species of Arachnida, Collembola, and Insecta. Arctic 16:175-180.

Oosterbroek, P. 1979. The western Palaearctic species of *Nephrotoma* Meigen, 1803 (Diptera, Tipulidae). Part 5, Phylogeny and biogeography. Beaufortia 29:311-393.

______. 1984. A revision of the crane-fly genus *Nephrotoma* Meigen, 1803, in North America (Diptera, Tipulidae). Part II: The non-*dorsalis* species-groups. Beaufortia 34:117-180.

Pritchard, G. 1983. Biology of Tipulidae. Annual Review of Entomology 28:1-22.

Savchenko, E.N. 1961. [Family Tipulidae, Subfamily Tipulinae, Genus *Tipula* L. (Part 1)]. Fauna SSSR No. 79:1-487. (In Russian).

Teskey, H.J. 1979. 42. Diptera. In: Canada and Its Insects Fauna. Edited by: H.V. Danks. Memoirs Entomological Society of Canada No. 108:389-424.

Theowald, Br. 1971. Drei holarktische *Symplecta*-arten (Diptera, Limoniidae). Beaufortia No. 247(19):47-54.

ENERGY BUDGET FOR ACTIVITY AND GROWTH OF A HIGH-ARCTIC INSECT, Gynaephora groenlandica (WOCKE) (LEPIDOPTERA: LYMANTRIIDAE)

Olga Kukal[1]

Abstract: Growth and development of the woolly-bear caterpillar (Gynaephora groenlandica) are confined to a brief period of activity interrupted before each mid-summer of its 14 year life-cycle. Consequently, I investigated the physiological consequences of thermoregulatory and feeding behaviour. Basking is pivotal to larval thermoregulation since it raises body temperature by as much as 25°C above the ambient temperature (T_a ~5°C), which is often below the larval developmental threshold. Larval growth-rate and assimilation efficiency is optimized at T_b ~15°C, whereas at high basking T_b of ~30°C, the assimilation efficiency decreases with increased maintenance metabolism and ingestion-rate. Conversely, at low T_b of ~5°C, the growth-rate is lower as is the rate of ingestion. Changes in metabolic state influence the metabolic-rate; highest in feeding larvae and decreasing progressively for digesting, moving, starved, cold-acclimated and inactive larvae. Influence of temperature on digestion-rate and maintenance metabolism is the likely cause of the feeding behaviour pattern in G. groenlandica. The larvae maximize their assimilation efficiency by selective and seasonal feeding and also by raising their digestion-rate while basking. The larvae undergo "voluntary hypothermia" in order to avoid an energy deficit resulting from high maintenance metabolism during mid-season, when the energy content and food quality of Salix arctica declines. Since behaviours other than basking cause larval T_b to drop, basking plays a central role in the diel and sequential organization of larval behaviour. Movement, other than in search of new feeding sites is minimized, basking time is maximized and feeding is followed by basking. At low ambient temperatures basking prevails. Basking under optimal conditions leads to maximal rates of oxygen consumption at T_b >30°C, whereas below 5°C, oxidative metabolism is depressed. The larvae of G. groenlandica are thermoregulators, able to alter their developmental rate by changes in behaviour and feeding strategy.

Résumé: La croissance et le développement de la Gynaephora groenlandica se limitent à une courte période d'activité qui cesse avant le milieu de l'été, chaque année de son cycle biologique de 14 ans. J'ai donc étudié les conséquences physiologiques des comportements thermo-régulatoires et des comportements alimentaires chez l'espèce. L'exposition au soleil est un élément crucial pour la thermorégulation larvaire, étant donné qu'elle amène une hausse de la température du corps (T_b) qui peut atteindre 25°C au-dessus de la température ambiante (T_a) de ~5°C, ce qui est souvent inférieur au seuil de développement larvaire. Les taux de croissance de la larve et l'efficacité d'assimilation sont optimisés à une T_b de ~15°C, alors qu'à une T_b de ~30°C, l'efficacité d'assimilation diminue et le métabolisme de maintien et le taux d'ingestion sont à la hausse. À l'inverse, si la T_b est de ~5°C, le taux de croissance comme le taux d'ingestion sont plus bas. Des changements de l'état métabolique ont une influence sur le rythme du métabolisme, qui est plus élevé pour les larves qui se nourrissent et baisse graduellement pour celles qui digèrent, celles qui bougent, celles qui sont affamées, celles qui sont acclimatées au froid et celles qui sont inactives. L'influence de la température sur le taux de digestion et le métabolisme de maintien est la cause probable du modèle de comportement alimentaire de la G. groenlandica. Les larves portent au maximum leur efficacité d'assimilation par le biais d'une alimentation saisonnière et sélective et aussi en augmentant leur taux de digestion lors de l'exposition au soleil. Les larves se livrent à une "hypothermie volontaire" afin d'éviter un déficit d'énergie qui serait le résultat d'un métabolisme de maintien élevé en milieu de saison, quand l'apport d'énergie et la qualité de la nourriture du Salix arctica sont moindres. Étant donné qu'il existe des comportements autres que l'exposition au soleil qui amènent une baisse de la T_b, l'exposition au soleil occupe un rôle important dans l'organisation nycthémérale et séquentielle du comportement de la larve. Le mouvement, à part celui effectué lors de la recherche de sites alimentaires, est minimisé, la durée de l'exposition au soleil est maximisé et l'alimentation est suivie de l'exposition au soleil. À des températures ambiantes basses, l'exposition au soleil est l'activité dominante. L'exposition au soleil dans des conditions optimales conduit à des taux maximaux de consommation d'oxygène à une T_b de >30°C, tandis qu'en-dessous de 5°C, le métabolisme d'oxydation est diminué. Les larves de la G. groenlandica sont thermorégulatrices et ont la capacité de modifier leur taux de développement en changeant leurs stratégies d'alimentation et de comportement.

INTRODUCTION

Insects inhabiting polar and temperate regions show varying degrees of cold-adaptation in their active and inactive states. During the summer, active insects may modulate their

---

[1] Department of Biological Sciences, University of Notre Dame, Notre Dame, Indiana 46556, U.S.A.

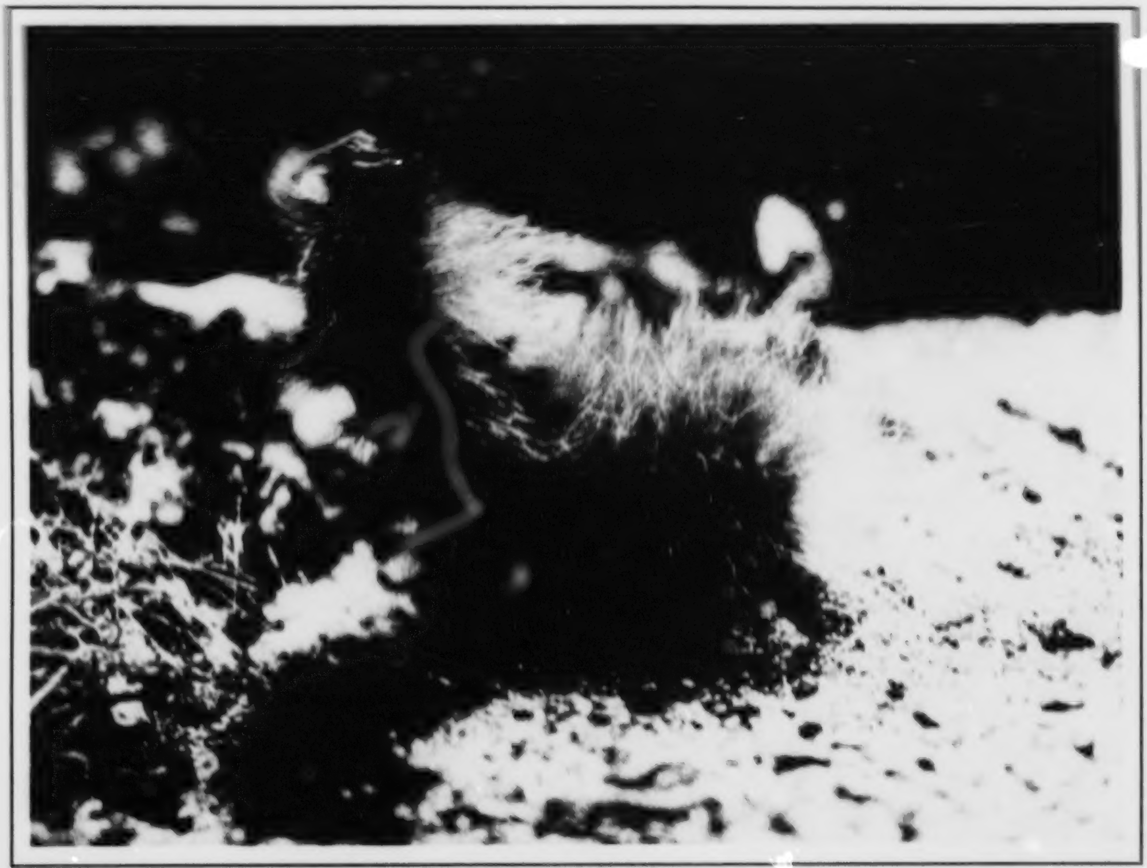


FIGURE 1: Woolly bear caterpillar (Gynaephora groenlandica).

metabolism by behaviourial thermoregulation (May 1979; Heinrich 1981), and few species show fixed metabolic compensation for cold (Scholander *et al.* 1953). Higher metabolic-rates at low temperatures may stem from increased enzyme concentrations, lowered activation energies, or from the synthesis of seasonal isozymes (Storey and Storey 1983; Hochachka and Somero 1985). During the winter most insects remain inactive, either in diapausing or quiescent state (Tauber *et al.* 1986). The diapause state, together with cold hardening, is usually linked to environmental cues such as temperature, photoperiod, thermoperiod or nutrition (Beck 1983). A few insect species avoid the cold periods by extensive migration to warmer regions (Danks 1978, 1981). Summer hiatus of activity (aestivation) is comparatively rare in insect life histories, but occurs in the High Arctic larvae of *G. groenlandica* (Kukal 1988; Kukal *et al.* 1988A).

The arctic woolly-bear caterpillar *Gynaephora groenlandica* (Wocke) (Figure 1) is endemic to the northernmost Arctic Islands and Greenland, and is one of the most northerly occurring representatives of the order Lepidoptera (Ferguson 1978). Consequently, it is exposed to an extreme environment characterized by wide climatic fluctuations, short summer seasons, low temperatures, xeric conditions, continuous daylight in summer, and continuous darkness in winter. At Alexandra Fiord lowland, growth and development of *G. groenlandica* are confined to a brief period of activity within each summer of its 14 year life-cycle (Kukal and Kevan 1987). The adult and early larval stages last less than 6% of the entire life-cycle, and are entirely dependent on the energy stored by later instar larvae - the only overwintering phase. During the summer, more than two-thirds of the larval stages are killed by insect parasitoids (Kukal and Kevan 1987). In comparison, the winter mortality is at most 13% of the population, which suggests biotic as opposed to abiotic population regulation (Kukal and Kevan 1987). The insect is well adapted to cold, especially in its larval stage which overwinters in frozen state and resumes feeding for a short period during the summer.

Solar radiation is a scarce and often limiting resource in the High Arctic (Bliss 1977; Danks 1981; Svoboda and Freedman 1988). The heat budget is limited seasonally by the number of sunny days, and also daily by changes in intensity of sunshine with angle of the sun above the horizon. The development of *G. groenlandica* larvae at Alexandra Fiord lowland is therefore probably enhanced by their behavioural use of sunshine. The larvae of *G. groenlandica* (Kukal *et al.* 1988A) and *G. rossii* (Kevan *et al.* 1982), as well as some other High Arctic insects (Bertram 1935; Krog 1955; Kevan and Shorthouse 1970; Kevan 1975), raise their body temperatures by basking. Although elevation of body temperature enhances development (May 1979; Scriber and Slansky 1981), *G. groenlandica* requires 14 years to complete its life-cycle. Basking may enhance the rate of larval development but probably also interferes with other maintenance activities, such as feeding.

Evolution of insect life-cycles has been ascribed to variation in consumption and use of food (Slansky and Scriber 1985). In spite of the difficulties associated with construction of nutritional energy budgets (Wightman 1981; McEvoy 1985), many insect species have been examined (cf. Slansky and Scriber 1985). The focus, however, has been on insects inhabiting regions other than the physically-limiting arctic environment. Consequently, I investigated the nutritional energy budget of *G. groenlandica*. Despite the short summer characteristic of the species' habitat, the larvae cease foraging prior to mid-summer (Kukal and Kevan 1987). This interrupted summer feeding may contribute to the long life-cycle of the moth.

The preferred, although not entirely exclusive, food for arctic woolly-bear caterpillars is the arctic willow (*Salix arctica*) (Kukal and Kevan 1987). *Salix arctica* is a deciduous species. It synthesizes new, nutrient-rich tissues as a food source, compared with other arctic plant species (primarily evergreens and wintergreens), which are more depauperate - particularly in their reserves of tissue nitrogen and total non-structural carbohydrates (TNC) (Chapin *et al.* 1980, 1986; Dawson 1987). Together with purple saxifrage (*Saxifraga oppositifolia*), the arctic willow has the earliest new growth available at the onset of summer (Bliss 1977; Svoboda and Freedman 1988). The young buds and shoots contain very high levels of nutrients and carbohydrates, which decline and are translocated to other plant parts by mid-season (Dawson 1987). Depletion of nutrients and carbohydrates from *S. arctica* is accompanied by a mid-summer buildup of secondary metabolites (Dawson 1987). Could this change in food quality influence the feeding behaviour and metabolic state of *G. groenlandica* larvae?

The general aim of this study was to investigate the thermoregulatory behaviour of larvae in relation to their daily activity pattern and feeding energy budget. The sequential and temporal organization of different types of behaviour was analyzed and related to changes in body temperatures and metabolic rate. The feeding activity of *G. groenlandica* larvae was related to growth-rate and assimilation efficiency as a function of temperature and food quality. Specifically investigated were: (1) seasonal phenology and comparmentation of nutrients, carbohydrates, caloric content and secondary metabolites of *Salix arctica*; (2) seasonal changes in feeding behaviour and metabolic state of *G. groenlandica* larvae; (3) the effect of temperature, feeding activity and digestion on the larval metabolic-rate; and (4) influence of temperature on the growth-rate and assimilation efficiency of the larvae. The ultimate aim is to provide a scheme for food utilization in a High Arctic insect limited by low temperatures and variations in food quality.

MATERIALS AND METHODS

Study Site

Investigations were conducted during 1982-1987 at two sites: Truelove Lowland, Devon Island and Alexandra Fiord Lowland, Ellesmere Island. Insect feeding-behaviour was examined mostly at Alexandra Fiord. Climate and microclimate were monitored at both sites using Campbell CR-5 and CR-21 data acquisition stations (Campbell Scientific, Logan, Utah) equipped with fine wire copper-constantan thermocouples, quantum and pyranometer sensors (LiCor Inc., Lincoln, Nebraska) for measuring solar and photosynthetically active radiation respectively (Dawson 1987; Henry 1987).

Behaviour

Larvae of *Gynaephora groenlandica* were observed during June 1983 and 1985 at Alexandra Fiord Lowland (Kukal et al. 1988A,B). Behavioural observations were made on larvae encountered on the open tundra and in a circular area of tundra (diameter ~6 m), containing approximately 40% *Dryas integrifolia*, 10% *Cassiope tetragona*, 10% *Saxifraga oppositifilia* and 10% *Salix arctica*, that was surrounded by snow.

The diel pattern of behaviour was determined by hourly recordings of the proportion of enclosed larvae (N=300) engaged in particular types of behaviour (i.e., basking, feeding, moving) over 24 hours. Sequential organization of behaviour was recorded for 10 larvae observed continuously from 13:00-17:00 hours on a sunny, calm day (ambient temperature: T_a = 8°C). Duration of different behaviours was scored by minutes for each larva, and frequencies of transitions between behaviours were analyzed in a transition matrix of preceding vs following behaviours, with the diagonal held to logical zeroes (assuming a behaviour cannot follow itself, Fagen and Young 1978). A kinematic graph of behavioural states and sequences was constructed from the transition matrix by showing average durations of different behaviours and frequencies of transitions among different behavioural states (Sustare 1978). Transitions from one behaviour to another were tested for significance with the X^2-statistic by collapsing the table about the cell of interest to form a 2 x 2 contingency table (Leonard and Ringo 1978; Nelson and Fraser 1984).

Physiological Effects of Behaviour

Effects of different types of behaviour on larval body temperatures (T_b) were recorded in the enclosure at constant ambient conditions. Larval T_b was obtained in 2-4 secs by indenting the dorsal cuticle with the tip of a copper-constantan thermocouple (Bailey Bat-12; Type MT-29/1, time constant = 0.25 sec, diameter = .33 mm) read to the nearest 0.1°C. Air and substrate temperatures (T_a recorded ~1 m above larvae; T_s within 1 cm from larvae) were always measured with the same thermocouple as T_b. The changes in T_b of eight larvae were followed in the field; records of T_b, T_a and T_s were made every 0.5-2 hours over a 38-hour period beginning at 10:00 hours. The mean T_b for larvae basking, moving, feeding, molting, spinning or for parasitized larvae were compared by t-tests. Coefficients of variation were computed as indicators of variance within each behavioural state. Effects of different ambient conditions on T_b were compared for larvae basking and spinning cocoons. The effect of sun, cloud cover, wind, and time of day on larval T_b was tested by measuring T_b of basking and spinning larvae while only one of the ambient conditions varied. The degree of cloud cover was estimated by a measurement of the relative light intensity with a "supersensitive darkroom meter" (S & M Model A-3, Science and Mechanics, New York), and wind velocity was recorded with an anemometer at 0.25 m height above ground. T_b of larvae basking at noon without cloud cover were compared to those of larvae basking at midnight, at noon with cloud cover, and in sun with wind from the direction of insolation.

Oxygen Consumption at Different Body Temperatures

Oxygen-consumption rates were measured with an Amotek S-3A Applied Electrochemistry oxygen-analyzer capable of measuring to 0.001% 0_2-concentration using a flow-through system of 30 ml volume. The excurrent air was desiccated and depleted of CO_2 by passing it through a water and CO_2 absorbent before being pumped to a Model N-37M sensor. Readings were taken every 30 minutes over 3 hours for three groups of larvae: (1) actively feeding prior to measurements; (2) active but starved; and (3) "inactive" (i.e., immobile and spinning hibernacula, therefore presumably aestivating; see Kukal and Kevan 1987). Ten larvae from each of the three groups were enclosed in a chamber with a thermocouple and their rate of oxygen consumption was recorded over a range of temperatures from 0-50°C. The larvae were allowed to equilibriate for 30 minutes at each temperature recorded.

Larval Feeding Behaviour on the Tundra

Host plant preference was determined by observation of larvae feeding on the tundra over a period of three days at the onset and three days at the end of their feeding season in June 1987 (cf. Kukal and Dawson 1988). The species and plant part eaten was recorded for 200 larvae observed at each of the two periods. Preference for certain parts of *Salix* was estimated as the feeding periods allocated to leaves, buds, or catkins for 30 different larvae. Feeding larvae (N=10) were brought back into the laboratory, their guts were dissected out and examined for microbial symbionts.

Seasonal Trends in Food Quality and Availability

Six, entire plants were carefully excavated each week over the growing-season. Each plant was washed of all soil, blotted dry and sorted into leaves, reproductive structures, above- and below-ground shoots, fine roots and taproots. These tissues were weighed fresh and subsequently dried at 80°C in a force-draft oven to a constant weight. Dried samples were diced, thoroughly mixed, ground to 1 mm (20 mesh screen) in a Wiley Mill and analyzed for macronutrients (NPK) and caloric content as outlined by Dawson (1987). Total nonstructural carbohydrates (TNC) analyses followed a modified version of the methods outlined by Allen *et al.* (1974). Six individuals of *S. arctica*, harvested at three times during the 1985 growing-season, were used for the carbohydrate analyses. Plants were harvested and prepared as above, fixed immediately in boiling 80% EtOH (plus ~1 g of sodium bicarbonate) and sealed in a glass jar for transport to the laboratory. Tissue samples from the 1984 and 1985 samples were also prepared and analyzed for secondary plant metabolites following the methods of Bryant *et al.* (1983).

Temperature Influence on Growth-Rate and Assimilation Efficiency

Larvae collected at Alexandra Fiord throughout their feeding period in June 1987 were maintained in the laboratory at 5°, 15°, and 30°C under constant light for one month (July). *Salix arctica* was collected at Alexandra Fiord between 15-29 June, and kept near 0°C in the dark. Thirty larvae (instar IV, V) at each of the three incubation temperatures were kept in separate containers in groups of 10 and fed ample arctic willow. Each week the larvae and their dried frass (excreta) were weighed, old food removed, dried and weighed and ~50 g of fresh food replenished. Because the leaves were removed (preventing translocation) and kept in the dark (preventing photosynthesis and other light reactions), it can be assumed that food quality did not change significantly over the experimental period. The low-temperature larvae required only bi-weekly feeding. Dry weight of larvae was estimated from a standard proportion of fresh to dry weight. Amount ingested was determined from a standard relationship between fresh and dry weight of willow which precluded an error introduced by desiccation of food over the feeding period. Rates of growth and efficiencies of food consumption at different temperatures were computed as in Slansky and Scriber (1985). The nitrogen levels in frass excreted by larvae incubated in the laboratory at 15° vs 30°C was compared with frass collected from larvae in nature. Two hundred larvae were held in a wooden box exposed to daily temperature and light changes. They were fed ample willow throughout June and then their frass was collected, dessicated and analyzed for nitrogen content as described above.

The Effect of Feeding and Digestion on Larval Metabolism

Metabolic-rates of late instars were measured with an oxygen analyzer as described previously. Individual larvae (N=10) were placed in a 10 ml flask with or without *Salix* leaves and their oxygen uptake was detected by a Model N-37M sensor in a flow-through system where the intake and outlet-air was filtered through water and carbon dioxide absorbents. The flow rate of air was maintained at 125 ml O_2/hr by a pump, and the oxygen inside the flask was continuously compared to the ambient O_2 concentration.

Comparisons were made between oxygen update at 25°C by feeding larvae, digesting, moving, cold-acclimated and inactive larvae in hibernacula. From these data the length of the digestion period was estimated. Standard metabolic-rate was asigned from the comparison of larvae after digestion with larvae in hibernacula.

RESULTS

Behaviour

Larvae spent 95% of their time basking, moving or feeding and % immobile in shaded crevices ("hiding") or grooming. More than half of the total time ws spent basking, followed by feeding (20%) and moving (15%) (Figure 2). In behavioural squences, basking most often followed feeding (X^2 = 50.22, p <.005). In order of decreasing frequency were the behavioural transitions from feeding to basking (X^2 = 14.93), then moving to basking (X^2 = 13.11), feeding to moving (X^2 = 8.53), hiding to moving (X^2 = 6.74), and finally, moving to hiding (X^2 = 5.18). All other behavioural transitions were not significant. The transitions between basking and feeding and between moving and hiding were reversible, however, the transitions from basking to moving to feeding were rare and consequently not statistically significant. Over the course of 24 hours, the larvae moved or fed primarily around mid-day, but most basked near midnight (Figure 3).

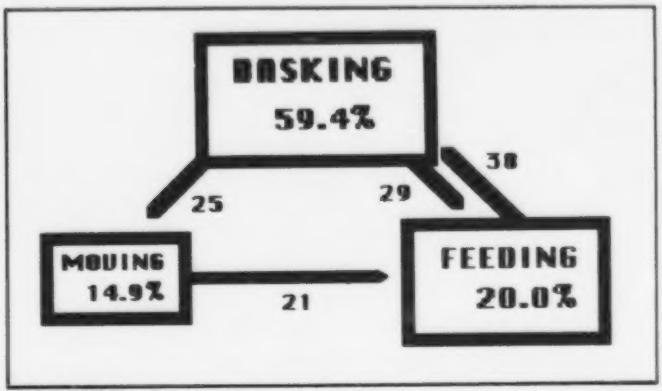


FIGURE 2: Frequency and sequential organization of major behaviours in eight G. groenlandica larvae. Relative sizes of squares and arrows indicate the frequency of occurrence by percentage of time spent in particular behaviour (within squares), and the number of times one behaviour followed another (arrows) (see text for details). Infrequent behaviours, such as grooming and hiding among vegetation clumps, are excluded from the kinematic graph.

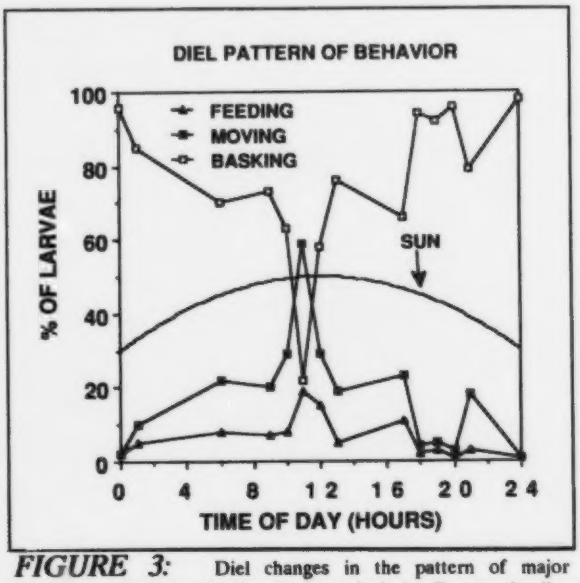


FIGURE 3: Diel changes in the pattern of major behaviours (basking, feeding and moving) in G. groenlandica larvae (N=~500) in a natural enclosure of the tundra under sunny, calm conditions (T_a at 1 m = 2.0-6.3°C). Change in the height of sun above the horizon is indicated; minimum at 10° and maximum at 33° above the horizon.

Physiological Effects of Behaviour

Behavioural changes significantly affected larval body temperatures (Table 1). Larvae attained a maximal T_b of 30.5°C by basking. Moving caused the mean T_b to drop by approximately 4°C, and a further significant drop occurred when feeding commenced. The body temperatures of moulting and spinning larvae were similar to those observed in feeding and parasitized larvae. All of the mean T_b at different behaviours were significantly different by t-test (p <.001) from basking T_b, and the T_b of moving larvae were statistically different from the feeding larvae (p <.01). Body

TABLE 1: MEAN BODY TEMPERATURES OF G. groenlandica LARVAE IN DIFFERENT BEHAVIOURS OBSERVED BETWEEN 12:00-13:00 HOURS, 25 JUNE, ON THE TUNDRA (SUNNY, CALM, T_a= 7°C, T_s = 16.5°C).

BEHAVIOUR	N	MEAN[1]	STANDARD DEVIATION	COEFFICIENT OF VARIATION
Basking	20	30.5^a	2.2	7.2%
Feeding	14	23.9^b	2.2	9.2
Moving	15	26.7^b	2.6	9.7
Spinning	22	24.1^b	4.3	17.8
Molting	5	25.5^b	4.0	15.7
Parasitized	18	24.3^b	3.1	12.8

[1] Sample means followed by a different letter are significantly different by t-test ($p < .001$) from the mean T_b of basking larvae. Mean T_b of feeding vs moving larvae are also significantly different by t-test ($p < .01$).

TABLE 2: CHANGES IN MEAN BODY TEMPERATURE OF BASKING LARVAE OF G. groenlandica (N=20-30) UNDER DIFFERENT WEATHER CONDITIONS AND DURING DIFFERENT TIMES OF DAY (T_a at 1m = 2-6.5°C).

CONDITIONS	MEAN BODY TEMPERATURE ±S.D.[1]
Noon/sunny/calm	30.5 ± 2.2^a
Noon/sunny/windy	14.2 ± 1.8^b
Noon/cloudy/calm	12.4 ± 1.9^b
Midnight/sunny/calm	13.2 ± 2.8^b

[1] Sample means followed by a different letter are significantly different by t-test ($p<.001$).

temperatures of basking and spinning larvae were lowered by 16-18°C in cloud cover, wind and midnight sun (Table 2). All of the mean T_b at different ambient conditions showed significant differences by t-test ($p < .001$). Figure 4 shows the mean T_b of eight larvae followed in the field over 38 hours. Maximum T_b was reached at mid-day and minimum T_b at midnight; a trend also shown by T_a and T_s. Lower T_b was attained at mid-day on the first day under a partial cloud cover than on the second day which was sunny. Variation between body temperatures of individual larvae are reflected in the large standard deviation (± ~5°C) from the mean T_b.

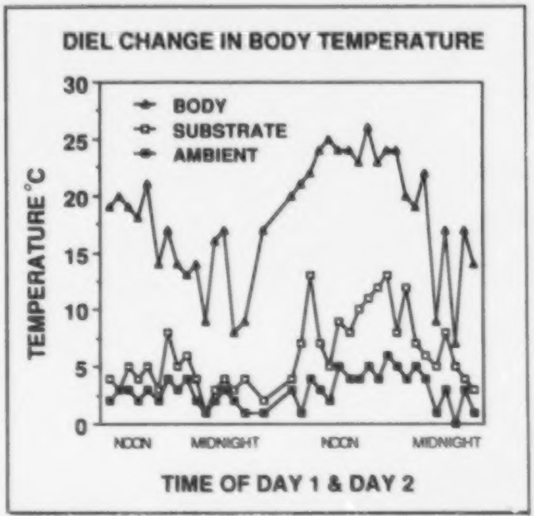


FIGURE 4: Diel changes in mean body temperature (± S.D. ≤5) of eight G. groenlandica larvae relative to ambient and substrate temperatures recorded nearly bi-hourly over two days (overcast day followed by a sunny one) on the open tundra.

Oxygen Consumption at Different Body Temperatures

The relationship between body temperature and oxygen consumption was exponential to sigmoidal in the three groups of larvae (Figure 5). The Q_{10} was lowest between 0-10°C for all groups of larvae. The highest Q_{10} for active larvae was between 10-20°C, whereas for starved larvae between 20-30°C. However, no significant difference was found between oxygen uptake in the three groups of larvae. Hence the "inactive" larvae were unlikely in aestivation, since their metabolic-rate was the same as in the active larvae. Similarly, starvation did not alter the larval metabolic-rate.

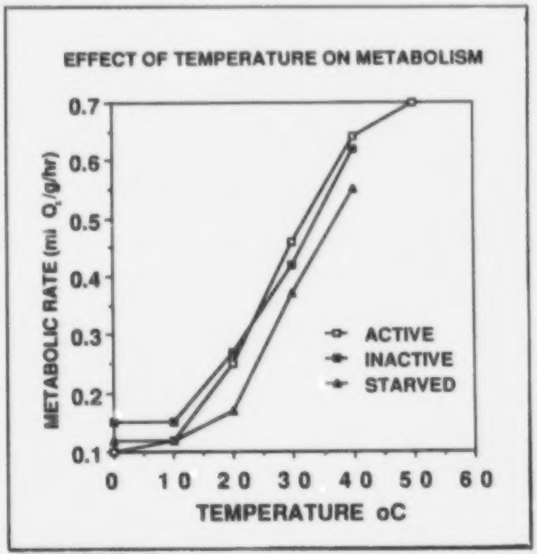


FIGURE 5: Metabolic-rate as a function of body temperature (range from 0-50°C) recorded for 10 actively feeding, active but starved and inactive larvae of G. groenlandica.

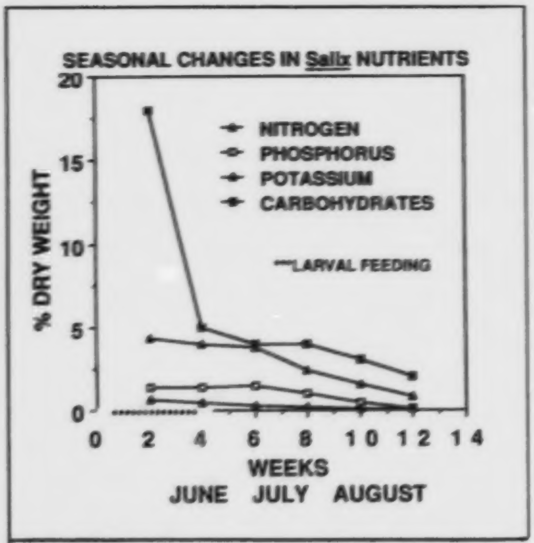


FIGURE 6: Seasonal variation in nutrient and carbohydrate (TNC) content of Salix arctica leaves in the High Arctic (N=17; mean values ± S.E. ≤1 for TNC; S.E. ≤0.1 for macro-nutrients). The period of G. groenlandica feeding activity is indicated.

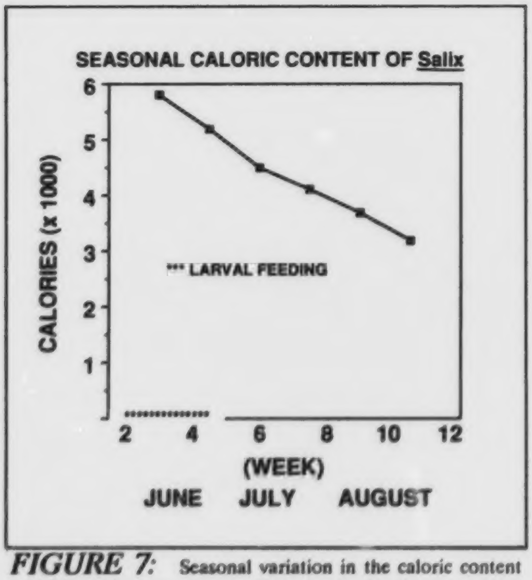


FIGURE 7: Seasonal variation in the caloric content of Salix arctica leaves in the High Arctic (N=5; mean values ± S.E. ≤3x10^{3}). The period of G. groenlandica feeding activity is indicated.

Feeding Behaviour on the Tundra

Ninety-seven percent of larvae (N=200) fed primarily on new leaf-buds of arctic willow (*Salix arctica*) at the onset of their feeding season. However, at the end of June, just prior to cessation of feeding, only 9% of larvae fed on new leaf-growth. At the onset of summer <3% of larvae fed on the flowers of purple saxifrage (*Saxifraga oppositifolia*) and on senescent leaves of arctic avens (*Dryas integrifolia*). As the frequency of feeding decreased there was no switch to a different food source or to a different plant part. The length of larval feeding period was only about 30% of the degree-days available for growth as indicated by the microclimatic measurements (Henry 1987). Feeding was usually followed by basking while digesting for approximately five hours. Feeding larvae (N=10) contained no bacterial symbionts in their guts.

Seasonal Trends in Resource Availability and Insect Feeding

Nutrient, carbohydrate and caloric-content of *S. arctica* leaves declines steadily over the course of the summer (Figures 6, 7). A particularly sharp decrease at the end of June is evident in the carbohydrate-content of leaves (Figure 6). Secondary plant metabolites, on the other hand, increase in concentration over the summer season (Figure 8).

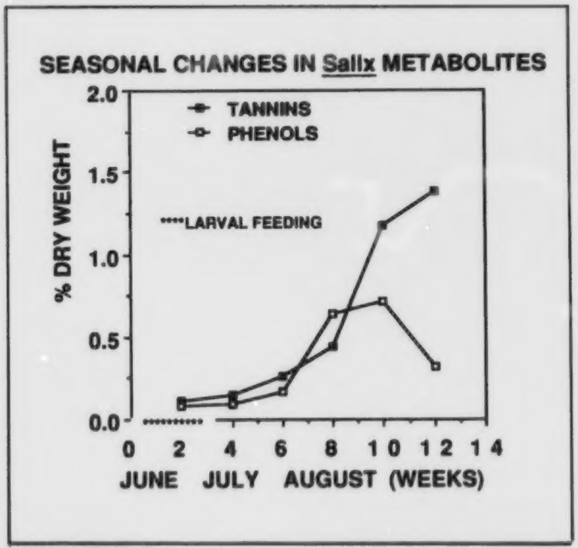


FIGURE 8: Seasonal variation in the secondary metabolites of *Salix arctica* leaves in the High Arctic (N=5; mean values ± S.E. ≤0.1). The feeding activity of *G. groenlandica* is indicated.

Temperature Influence on Growth Rate and Assimilation Efficiency

Larval growth rates and assimilation efficiencies are shown in Table 3. Growth rates were similar at 15° and 30°C (approximately double the rate at 5°C). However, the amount of *Salix* ingested and frass excreted varied between the three incubation temperatures, as did assimilation efficiencies. At the lowest temperature the amount ingested and egested was very low compared to the amounts of food processed at higher temperatures (Table 3). The amount ingested at 30°C was about four times the amount consumed at 15°C, and the

TABLE 3: TEMPERATURE INFLUENCE ON GROWTH RATE AND ASSIMILATION EFFICIENCY OF G. groenlandica LARVAE FEEDING ON Salix arctica[1].

INCUBATION TEMP.	LARVAL GROWTH RATE	FOOD INGESTED	FRASS EXCRETED	METABOLIC -RATE	ASSMILATION EFFICIENCY
	mg dry wt/larva/day (mg dry wt/mg larva/day)				
5°C	2.33 ± .33 (.008)	3.67 ± .67 (.012)	0.33 ± .13 (.001)	1.0 .033	70%[2]
15°C	4.67 ± 2.00 (.016)	16.67 ± 4.00 (.056)	5.00 ± 2.67 (0.17)	7.0 .023	40%
30°C	5.00 ± 2.00 (.017)	68.33 ± 5.00 (.227)	16.00 ± 2.33 (0.53)	47 .157	9.5%

[1] Each incubation temperature contained three groups of 10 larvae. Assimilation efficiency = % mass gain per mass ingested; metabolic-rate = (food ingested - excreted) - mass gain (Values = mean - ±1 S.E.) (mean dry wt of larva = .30 ± .05 g).

[2] Value overestimated due to the extended residence time of food in the gut at low temperatures.

TABLE 4: OXYGEN CONSUMPTION AT 25°C BY LARVAE IN DIFFERENT METABOLIC STATES; FEEDING, DIGESTING, STARVED, IN HIBERNACULA AND FOLLOWING COLD ACCLIMATION[1]

METABOLIC STATE	OXYGEN CONSUMPTION (ml/g/hr)[2]
Standard metabolism	0.06 ± .02 a
Starved larvae	0.06 ± .02 a
Moving larvae	0.11 ± .03 b
Feeding larvae	0.29 ± .03 c
Digesting larvae	0.17 ± .02 d
Larvae in hibernacula	0.07 ± .02 a
Low-temperature acclimation[3]	0.07 ± .02 a

[1] (N=10; Values = mean ± S.E.).

[2] Means followed by a different letter are significantly different by t-test (p>0.005).

[3] Larvae held at 5°C and in the dark for three months.

amount excreted was approximately three times more at the higher temperature. The corresponding assimilation efficiencies were 9.5% at 30°C, 40% at 15°C and 70% at 5°C. Dissections of guts indicate food retention in the guts of larvae incubated at 5°C.

The Effect of Feeding and Digestion on Larval Metabolism

The effect of metabolic state on respiration-rate is shown in Table 4. The starved larvae, cold-acclimated and inactive larvae within hibernacula, maintained basal metabolic-rates. This rate increased during movement, and further increase was evident when feeding ensued. Following feeding, approximately five hours of elevated metabolic-rate indicated a digestion period. The oxygen-consumption rate by digesting larvae was greater than in actively moving larvae.

DISCUSSION

Behavioural Thermoregulation

Sunshine-dependent behavioural thermoregulation is crucial for the survival of *G. groenlandica* at Alexandra Fiord, where low ambient (<5°C) and ground temperatures (usually <10°C) prevail during their brief activity in June (Kukal 1984, 1988C). Although the ambient and substrate temperatures gradually increase and peak in July, the intensity of incoming solar radiation declines after the summer solstice (Svoboda and Freedman 1988). The activity (i.e., feeding and basking on the tundra surface) of *G. groenlandica* larvae coincides with the period of most intense solar radiation during June.

The energy cost of different types of activities is best seen from the effect of different behaviours on body temperature, which can in turn be related to metabolic-rate. Maximal T_b in excess of the ambient temperature, which is attained by basking at mid-day, decreases by about 20% (-4°C) when behaviour changes to moving, feeding, molting or spinning. Fifty percent heat-loss (-17°C) occurs in basking larvae at midnight, under cloud cover at midday, or in strong wind. However, if the larvae stop basking at midnight and start moving they suffer a further 20% heat-loss, a total of 70% of body temperature attained by larvae basking at midday. Evidently, energy balance of larvae is influenced by the different behaviours, which are in turn affected by larval food status and habitat temperature. Raising body temperature in fed larvae likely enhances digestion rate by stimulating activity of gut enzymes since no bacterial flora is present to aid digestion. Thus body temperature and energy status of larvae is probably pivotal in controlling the type of behaviour. At higher T_b more energy can be obtained in a limited time from the food ingested, however, when energy from food is depleted, then feeding commences at the expense of energy lost as heat. On the other hand, at higher T_b the "maintenance metabolism" is probably increased, hastening use of energy reserves obtained from food, as noted in other thermoregulating ectotherms (Brett 1971).

The precarious energy balance is reflected in the daily behavioural pattern of larval *G. groenlandica* and in the sequential organization of different behaviours. Larvae spend most (60%) of their time basking (even during pupation the basking position is assumed), which increases their body temperature and metabolic rate, and may lead to an increased rate of digestion. Feeding activity provides the source of energy and ranks in its frequency second to basking, while movement, in search of food or new basking sites, ranks last. These three most prominent behaviours follow a definite sequence; most often from feeding to basking, less often from basking to feeding or from basking to moving and then feeding. Interestingly, the reverse sequence of behaviours from feeding to moving and then basking rarely occurs. This suggests an intimate reciprocity between basking and feeding, with movement restricted to finding new food sites or changing their basking position. During the course of a day the relative importance of the three behaviours changes; more larvae feed and move at midday, and relatively more larvae bask at night. This temporal partitioning of activity may be caused by lower ambient temperatures at night which lower larval T_b. During daytime, greater incoming solar radiation raises larval T_b enabling feeding and mobility. In contrast to *G. groenlandica*, the "thermally independent" gypsy moth (*Lymantria dispar*) larvae feed mostly in early mornings and evenings and are immobile at midday (Knapp and Casey 1986) - an adaptation attributed to the avoidance of predation and parasitism (Campbell 1981). Although more than two-thirds of *Gynaephora* are killed by parasitoids (Kukal and Kevan 1987), these "thermally dependent" larvae probably cannot sacrifice their basking time to hiding from parasitoids. The larvae probably "compromise" by maximizing development during the period of lowest parasitoid activity (Kukal and Kevan 1987).

Larval metabolic-rate increases exponentially with body temperature, even during starvation or apparent inactivity, and approaches zero below 10°C as in the majority of insects that also lack metabolic compensation to cold (Scholander *et al.* 1953). Consequently, without the aid of 24-hour sunlight to raise their T_b by as much as 20°C, the larvae would likely remain at most times below their developmental threshold temperature. Similar excess body temperatures have been recorded in basking larvae of the nearctic-alpine conspecific of *G. groenlandica*, *G. rossii* (Kevan *et al.* 1982). In contrast to the strict dependence of the arctic larvae on solar radiation, gypsy-moth larvae are "thermoconformers". Thermoregulation is apparently unnecessary for gypsy-moth larvae since the ambient temperature is well above their developmental threshold (Knapp and Casey 1986).

Conservation of heat by larvae is best viewed from an anatomical perspective. As the wind-tunnel experiments with *G. groenlandica* showed, the cooling rate is minimized by the dense, dark setae combined with radiant energy input (Kukal *et al.* 1988A). Larval setae create a boundary-layer of undisturbed air which, nevertheless, can be disrupted by high winds. The insulative quality of larval setae has also been demonstrated in the gypsy moth (Casey and Hegel 1981), and as shown by our results, this insulation can be greatly enhanced by insolation. Similarly, in the field, heat was best conserved as excess T_b at mid-day under sunny conditions, and further enhanced by the albedo effect of surrounding snow. Noteworthy is the decreased ability of larvae to warm up in the midnight sun (Kukal *et al.* 1988A).

The albedo effect may be involved in the disappearance of larvae from the tundra surface early in the arctic summer. Melting of snow from the larval habitat and surrounding ice-fields is the main cause of the sharp decrease in incoming radiation (Svoboda and Freedman 1988). In light of the strict dependence of these larvae on the sun's heat, it may be energetically more viable for them to cease feeding than to maintain activity at lower body temperature. This brief period available for feeding likely extends the developmental time of *G. groenlandica* to 14 years. The evolutionary strategy of *G. groenlandica* appears to involve a brief period of "maxithermy" (cf. Hamilton 1973) followed by a "voluntary hypothermia" (cf. Regal 1967) in mid-summer.

INFLUENCE OF TEMPERATURE ON GROWTH RATE AND ASSIMILATION EFFICIENCY

The larvae of *Gynaephora groenlandica* are energetically limited by the quantity and quality of their main food source, the buds and young leaves of *Salix arctica*. Larval feeding behaviour and assimilation efficiency is therefore expected to vary with seasonal changes in nutrient, carbohydrate and caloric content of *Salix* tissues (cf. Ayres and MacLean 1987; Chapin *et al.* 1986; MacLean and Jensen 1985). This variation in food quality is reflected in the restriction of larval feeding behaviour to June, when both the nutrient and carbohydrate content of the host plant is maximal. At this time the buds and new leaves contain the greatest concentrations of nutrients and carbohydrates, which in July are translocated to the reproductive parts. The willow catkins, however, are rarely consumed by the larvae. The observed larval response (i.e. cessation of feeding) to changing quality of their host plant is compensatory rather than inductory (cf. Slansky and Scriber 1985), where a behavioural change in the seasonal feeding pattern leads to physiological modification of assimilation efficiency and growth rate. These physiological changes are a direct consequence of larval "voluntary hypothermia" (Kukal *et al.* 1988A) caused by their hiding in vegetation or cracks near the permafrost. There is no evidence, however, of an inductory-type of response resulting in genetically programmed summer aestivation since the larval metabolic-rate does not decrease and, if provided with fresh willow, the larvae continue feeding beyond June.

Further support for the decreased quality of food before mid-season in July, and its possible link to the cessation of larval feeding, may be the increased concentrations of secondary metabolites in the older leaves of *Salix*. Although not directly correlated, the buildup of tannins and phenols may also function as a feeding deterrent to the larvae of *G. groenlandica* (Feeney 1970; Rosenthal and Janzen 1979; Haukioja *et al.* 1985).

The shortened feeding period extends the developmental life-cycle of *G. groenlandica* and consequently has an effect of reducing its fitness by reduced reproductive potential (Price *et al.* 1980). On the other hand, if larvae remain active throughout July they will be more susceptible to parasitoid attack (Kukal and Kevan 1987). It appears that the larvae do not use their physiological potential for growth during July because of the heavy mortality caused by parasitoids. Moreover, decreased energy available from the host plant in the form of starch results in a decreased physiological potential for larval-growth during July. Similarly, the decreased July levels of plant nutrients, nitrogen in particular, may affect larval feeding behaviour. Molting may represent as much as 27% of the nitrogen or caloric content of a gypsy-moth larva (Montgomery 1982). These comparable losses may be minimized in *G. groenlandica* by its feeding strategy: maximizing energy intake from food by selectivity (both spatially and temporally) and minimizing energy expenditure in activities (i.e. feeding, mobility, molting) while food quality is relatively poor. Natural selection in tundra environments is abrupt and evolution slow. This type of feeding strategy would be selectively favoured.

Superimposed on the decreased quality of food influencing larval feeding behaviour is the effect of temperature. Being ectothermic, the larvae depend on sunshine to raise their body temperature. By preferential orientation toward the sun the larvae can reach a body temperature of ~20°C above the ambient temperature (Kukal *et al.* 1988A). Consequently, by basking, the larvae may regulate their metabolic and digestion-rates; however, at very high body temperatures (e.g. ~30°C), the maximal energy gain from digestion is counter-balanced by simultaneous increase in maintenance metabolism. Larval body temperature drops but the metabolic-rate increases as soon as feeding or moving commences. Consequently, the time spent feeding compared to basking is an essential determinant of larval energy balance. Under sunny conditions, larvae tend to feed during the highest temperatures at mid-day and bask at night when they cannot attain the higher temperatures required for activity (>5-10°C) due to reduced incoming radiation. The larvae spend more than 60% of their time basking, and move primarily to feed. Since digestion requires approximately five hours, it is probably necessary for the larvae to maintain elevated body temperature by basking in order to activate digestive enzymes. The lack of bacterial symbionts underscores the importance of raised body temperature to aid digestion in *G. groenlandica*. The lack of symbionts may influence the length of ingestive vs digestive phase. The feeding periods in *G. groenlandica* larvae are interspaced with relatively long periods of digestion while basking. McEvoy (1984) estimated a median feeding period for the cinnabar moth to be 40 minutes – much longer than in the arctic larvae. Feeding cinnabar-moth larvae also increase their respiratory-rate, however, contrary to *G. groenlandica* no significant increase was shown in digesting larvae (McEvoy 1984).

Laboratory experiments indicate that larvae assimilate food and nitrogen (Kukal and Dawson 1988) most efficiently at 15°C as opposed to 5° or 30°C; taking into account that the assimilation rate obtained for 5° is an overestimate resulting from the increased residence time of food in the gut. Assimilation efficiency decreases with increasing temperature (30°C) despite the similar larval growth rate. This decrease is undoubtedly caused by increased maintenance metabolism through increased activity, ingestion and egestion rates. Assimilation of nitrogen at the lower temperature of 15° is greater than at 30°C. In contrast to other Lepidoptera inhabiting warmer regions, assimilation efficiency of *G. groenlandica* decreases rather than increases with a temperature rise to 30°C (Slansky and Scriber 1985). Despite the relatively low rates of food consumption and growth, the efficiency of conversion of ingested food in *G. groenlandica* larvae exceeds the mean value for other species of Lepidoptera (Table 5).

TABLE 5: FOOD UTILIZATION BY Gynaephora groenlandica COMPARED TO: (A) 29 SPECIES OF LEPIDOPTERA; (B) DATA FROM SLANSKY AND SCRIBER (1985).

	RGR[1]	RCR[2]	AD[3]	ECD[4]	ECI[5]
	(mg dry wt/day/mg)		%	%	%
A: *Gynaephora* at 5, 15, 30°C					
5°	.008	.012	91.7	72.7	66.7
15°	.016	.056	69.6	41.0	28.5
30°	.017	.227	76.7	9.8	7.5
B: Other Lepidoptera (Values = x/range; N=444-629)					
	0.38/.03-1.50	2.03/.27-6.90	53/16-97	40/2-87	20/1-78

[1] Relative growth rate.
[2] Relative consumption rate.
[3] (Approximate digestibility)=(food ingested-frass)/food ingested.
[4] (Efficiency of conversion)=biomass gained/(food ingested-frass).
[5] (Efficiency of conversion of ingested food) = AD x ECD.

On the tundra, larvae spent most of their time basking at "night" when the ambient temperature is about 5°C (cf. Kukal et al. 1988b). This behaviour correlates with the comparatively low metabolic and digestive rates measured in the laboratory. At high temperatures approaching ~30°C the larvae start feeding. This may stem from the high energy requirements for maintenance metabolism reflected in high food consumption in the feeding experiment at 30°C. The intermediate incubation temperature of 15°C simulates the average body temperature of larvae in nature during their activity period in June.

Although the larval growth rate at 15°C is similar to the rate at 30°C, the assimilation efficiency is better because the energy loss in metabolism is much lower at the lower temperature. Supportive of the optimal intermediate temperature is the relatively high nitrogen content of larval frass following incubation at 30° vs 15°C (Kukal and Dawson 1988). An analogous study of growth rate by optimization of food assimilation and maintenance metabolism was performed on sockeye salmon (Brett 1971). Although the organisms studied are not closely related, they show similar energy budgeting in terms of feeding strategy and thermoregulation characteristic of ectotherms (May 1979). The salmon feed only at dawn and dusk, descending to lower depths where lower temperatures reduce their energy expenditure in maintenance metabolism while digestion takes place. The fishes' final perferendum temperature is 15°C (Brett 1971).

In his review of insect-plant relationships in the Arctic, Danks (1986) addresses the relative importance of physical vs biological constraints on the interdependence between herbivores and their plant hosts. He suggests that the decreasing ratio of herbivores to host plant species indicates an increasing influence of physical constraints over herbivores at high latitudes. The prevailing physical constraints may result in decreased specialization of arctic plant feeders i.e., more frequent polyphagy or oligophagy and lack of synchrony with plant phenology and resource allocation (Danks 1986). Chemical plant defenses, although common in temperate and tropical regions, have been rarely documented in the Arctic. An extreme case is exemplified by an Alaskan species of *Salix sitchensis* showing a defensive response to damage that can be pheromonally-communicated to neighbouring plants (Rhodes 1985). This study indicates a possible correlation between a buildup of tannins and phenols in *Salix arctica* and the feeding hiatus in *G. groenlandica* larvae. However, it is difficult to determine a single cause for the cessation in feeding prior to mid-season. Another likely cause may be the abrupt decline in the level of starch in the buds and young willow leaves that provide the primary source of energy for the larvae. If the larvae already exists "at the edge" in terms of their energy budget for growth and development, this decline in energy stores of their host plant may be crucial to maintenance of larval activity. Furthermore, the increased July ambient temperatures (Svoboda and Freedman 1988) probably raise the maintenance metabolism, which may exceed the energy demands for growth, especially in light of the declining food quality. Consequently, it may be advantageous for the larvae to undergo "voluntary hypothermia"; stop feeding and hide among vegetation and crevices, where close to the permafrost layer the larval body temperatures range between 0-5°C. The result is a lowered metabolic-rate and maintenance metabolism which enables storage of energy compounds, such as glycogen, for the synthesis of winter cryoprotectants (Kukal *et al.* 1988B). The metabolic-rate of larvae (presumably readying themselves for winter) in hibernacula is equivalent to the basal metabolic-rate of "inactive" larvae. This suppression of metabolic-rate may be adaptive in conserving the energy stores of larvae, and appears to be mainly temperature-regulated.

The insect-plant interaction between *G. groenlandica* larvae and *Salix arctica* reveals the importance of both, physical and biotic factors in influencing the insect's life-cycle and development. Temperature plays a crucial role in optimizing growth rate offset by maintenance metabolism. Host plant phenology and resource allocation influences the feeding pattern of *G. groenlandica* larvae. Concurrent increase in temperature and decrease in food quality probably confines the larval feeding activity to June, thereby extending the moth's life-cycle to 14 years at the Alexandra Fiord Lowland.

ACKNOWLEDGEMENTS

My research was supported by grants from the Polar Continental Shelf Project, Arctic Institute of North America, the Indiana Academy of Science, the IBM Women in Science Fund (University of Notre Dame), the Zahm Travel Grant (University of Notre Dame) and by a National Science Foundation grant to J.G. Duman. B. Heinrich (University of Vermont, Burlington) collaborated in investigating behavioural thermoregulation, and T.E. Dawson (University of Utah, Salt Lake City) provided the plant data for the study of growth rate and assimilation efficiency of *Gynaephora*. M. Kaufman (Kellogg Biological Station, Michigan State University) examined the guts of larval *G. groenlandica* for potential symbionts. J.G. Duman, P.G. Kevan and E.D. Walker are acknowledged for their ideas and comments on the manuscript. J.G. Duman, B. Heinrich, A.S. [illegible] and Kerry Temple were great research and survival companions in the Arctic. We are also much indebted to the Polar Continental Shelf Project personnel for logistic support in the field.

REFERENCES

Allen, S.E., H.M. Grimshaw, J.A. Parkinson, and C. Quanrmby. 1974. Chemical analysis of ecological materials. John Wiley and Sons, New York.

Ayres, M.P. and S.F. MacLean. 1987. Development of birch leaves and the growth energetics of *Epirrita autumnata* (Geometridae). Ecology 68(3):468-558.

Beck, S.D. 1983. Insect thermoperiodism. Annual Review of Entomology 28:91-108.

Bertram, G.C.L. 1935. The low temperature limit of activity of arctic insects. Journal of Animal Ecology 4:35-42.

Bliss, L.C. (Editor). 1977. Truelove Lowland,Devon Island, Canada: A High Arctic ecosystem. University of Alberta Press, Edmonton. 714 pp.

Brett, J.R. 1971. Energetic responses of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon (*Oncorhynchus nerka*). American Zoologist 11:99-113.

Bryant, J.P., F.S. Chapin, and D.R. Klein. 1983. Carbon/nutrient balance of boreal plants in relation to vertebrate herbivory. Oikos 40:357-368.

Campbell, R.W. 1981. Population dynamics. In: The Gypsy Moth: Research toward Integrated Pest Management. Edited by: C.C. Doane and M.L. McManus. United States Department of Agriculture, Washington, D.C. pp. 65-214.

Casey, T.M. and J.R. Hegel. 1981. Caterpillar setae: insulation for an ectotherm. Science 214:1131-1133.

Chapin, F.S., D.A. Johnson, and J.D. McKendrick. 1980. Seasonal movement of nutrients in plants of differing growth form in an Alaskan tundra ecosystem: implications for herbivory. Journal of Ecology 68:189-209.

Chapin, F.S., J.D. McKendrick, and D.A. Johnson. 1986. Seasonal changes in carbon fractions in Alaskan tundra plants of differing growth form: implications for herbivory. Journal of Ecology 74:707-731.

Danks, H.V. 1978. Modes of seasonal adaptations in the insects. I. Winter survival. Canadian Entomologist 110:1167-1205.

______. 1981. Arctic arthropods. A review of systematics and ecology with particular reference to the North American fauna. Entomological Society of Canada, Ottawa. 608 pp.

______. 1986. Insect/plant interactions in arctic regions. Revue d'Entomologie du Québec 31(1,2):52-75.

Dawson, T.E. 1987. Comparative ecophysiological adaptations in arctic and alpine populations of a dioecious shrub, *Salix arctica* Pall. Ph.D. thesis, University of Washington, Seattle.

Fagen, R.M. and D.Y. Young. 1978. Temporal patterns of behaviour: durations, intervals, latencies and sequences. In: Quantitative Ethology. Edited by: P.W. Colgan. Wiley and Sons, New York. pp. 79-114.

Feeny, P. 1970. Seasonal changes in oak leaf tannins and nutrients as a cause of spring feeding by winter moth caterpillars. Ecology 51:565-581.

Ferguson, D.C. 1978. Noctuoidea, Lymantriidae. In: The Moths of North America North of Mexico, Fasc. 22.2. Edited by: R.B. Dominick *et al.* E.W. Classey Ltd. and The Wedge Entomological Research Foundation. London. pp. 17-21.

Hamilton, W.J. 1973. Life's color code. New York, McGraw-Hill.

Haukioja, E., P. Hiemela, and S. Siren. 1985. Foliage phenols and nitrogens in relation to growth, insect damage, and ability to recover after defoliation in the mountain birch *Betula pubescens* spp *tortuosa*. Oecologia 65:214-222.

Heinrich, B. (editor). 1981. Insect thermoregulation. John Wiley and Sons, New York. 328 pp.

Henry, G.H.R. 1987. Ecology of sedge meadow communities of a polar desert oasis: Alexandra Fiord, Ellesmere Island, Canada. Ph.D. thesis, University of Toronto, Toronto, Ontario. 272 pp.

Hochachka, P.W. and G.N. Somero. 1985. Biochemical adaptation. Princeton University Press, Princeton. 537 pp.

Kevan, P.G. 1975. Sun tracking solar furnaces in High Arctic flowers: significance for pollination and insects. Science 189:723-726.

Kevan, P.G., T.J. Jensen, and J.D. Shorthouse. 1982. Body temperatures and behavioural thermoregulation of High Arctic woolly-bear caterpillars and pupae (*Gynaephora rossii*, Lymantriidae: Lepidoptera) and the importance of sunshine. Arctic and Alpine Research 14:125-136.

Kevan, P.G. and J.D. Shorthouse. 1970. Behavioural thermoregulation by High Arctic butterflies. Arctic 23:268-279.

Knapp, R. and T.M. Casey. 1986. Thermal ecology, behavior, and growth of gypsy moth and eastern tent caterpillars. Ecology 67(3):598-608.

Krog, J. 1955. Notes on temperature measurements indicative of spacial organization in arctic and subarctic plants for utilization of radiated heat from the sun. Physiologia Plantarum 8:836-839.

Kukal, O. 1984. Life history and adaptations of a High Arctic insect, *Gynaephora groenlandica*) (Wocke) (Lepidoptera: Lymantriidae). M.Sc. thesis, University of Guelph, Guelph, Ontario. 108 pp.

______. 1988. Behavioral and physiological adaptations to cold in a freeze tolerant High Arctic insect, *Gynaephora groenlandica* (Wocke) (Lepidoptera: Lymnatriidae). Ph.D. thesis, University of Notre Dame, Notre Dame, Indiana.

Kukal, O. and T.E. Dawson. (in press). Feeding "on the edge": temperature and food quality influences on feeding behavior, assimilation efficiency and growth rate of arctic woolly-bear caterpillars. Oecologia.

Kukal, O. and P.G. Kevan. 1987. The influence of parasitism on the life history of a high arctic insect, *Gynaephora groenlandica* (Wocke) (Lepidoptera: Lymantriidae). Canadian Journal of Zoology 65:156-163.

Kukal, O., B. Heinrich, and J.G. Duman. 1988A. Behavioral thermoregulation in the freeze tolerant arctic caterpillar, *Gynaephora groenlandica*. Journal of Experimental Biology 138:181-193.

Kukal, O., A.S. Serianni, and J.G. Duman. 1988B. Glycerol metabolism in a freeze-tolerant arctic insect: An in vivo 13-C NMR study. Journal of Comparative Physiology, B158:175-183.

Leonard, S. and J.M. Ringo. 1978. Analysis of male courtship patterns and mating behavior of *Brachymeria intermedia*. Annals of the Entomologcal Society of America 71:817-826.

MacLean, S.F. and T.S. Jensen. 1985. Food plant selection by insect herbivores in Alaskan arctic tundra: the role of plant life form. Oikos 44:211-221.

May, L.M. 1979. Insect thermoregulation. Annual Review of Entomology 24:313-349.

McEvoy, P.B. 1984. Increase in respiratory rate during feeding in larvae of the cinnabar moth *Tyria jacobaeae*. Physiological Entomology 9:191-195.

______. 1985. Balancing insect energy budgets. Oecologia 66:154-156.

Montgomery, M.E. 1982. Life-cycle nitrogen budget for the gypsy moth, *Lymantria dispar*, reared on artificial diet. Journal of Insect Physiology 28:437-442.

Nelson, M.C. and J. Fraser. 1984. Communication in the courtship of a Madagascan hissing cockroach. I. Normal courtship. Animal Behaviour 32:194-203.

Price, P.W., C.E. Bouton, P. Gross, B.A. McPherson, J.N. Thompson, and A.E. Weiss. 1980. Interactions among three trophic levels: influence of plants on interactions between insect herbivores and natural enemies. Annual Review of Ecological Systematics 11:41-65.

Regal, P.J. 1967. Voluntary hypothermia in reptiles. Science 155:1551-1553.

Rhoades, D.F. 1985. Pheromonal communication between plants. In: Chemically Mediated Interactions between Plants and Other Organisms. Edited by: G.A. Cooper-Driver, T. Swain and E.E. Conn. Plenum Publishing Corp., New York. pp. 195-218.

Rosenthal, G.A. and D.H. Janzen. 1979. Herbivores: their interaction with secondary plant metabolites. Academic Press, New York.

Scholander, P.F., W. Flagg, R.J. Hoch, and L. Irving. 1953. Climatic adaptation in arctic and tropical pokilotherms. Physiological Zoology 26:67-92.

Scriber, J.M. and F. Slansky, Jr. 1981. The nutritional ecology of immature insects. Annual Review of Entomology 26:183-211.

Slansky, F. Jr. and J.M. Scriber. 1985. Food consumption and utilization. In: Comprehensive Insect Physiology, Volume 4, Chapter 3. Edited by: G.A. Kerkut and L.I. Gilbert. Pergamon Press, Oxford. pp. 87-163.

Storey, K.B. and J.M. Storey. 1983. Biochemistry of freeze tolerance in terrestrial insects. Trends in Biochemical Sciences 8:242-245.

Sustare, B.D. 1978. Systems diagrams. In: Quantitative Ethology. Edited by: P.W. Colgan. Wiley and Sons, New York. pp. 275-311.

Svoboda, J. and B. Freedman (Editors). 1988. Ecology of a High Arctic lowland oasis, Alexandra Fiord (78°53'N, 75°55'W), Ellesmere Island, N.W.T., Canada. University of Toronto Press, Toronto.

Tauber, M.J., C.A. Tauber, and S. Musaki. 1986. Seasonal adaptations of insects. Oxford University Press, New York. 411 pp.

Wightman, J.A. 1981. Why insect energy budgets do not balance. Oecologia 50:166-169.

August 1, 1979
Alexandra Fiord
Ellesmere Island

Illustrated by Brenda Carter

FISHES, BIRDS AND MAMMALS

PRIORITIES FOR ICHTHYOLOGICAL RESEARCH IN THE CANADIAN ARCTIC ARCHIPELAGO

Don E. McAllister[1]

Abstract: Although much information is already available on fishes of the Canadian Arctic Islands, improved sampling is required involving collection of: (1) species not already represented in national collections; (2) deepwater fishes; (3) midwater fishes; (4) fishes in the south-central islands; (5) fishes in the Queen Elizabeth Islands; (6) fishes in winter. A book on the fishes of Arctic Canada is needed.

Résumé: Quoi que l'on connaisse déjà bien les poissons des îles de l'Arctique canadien, il faudrait améliorer l'échantillonnage par le prélèvement de: (1) certaines espèces qui ne figureraient pas déjà dans les collections de musées nationaux; (2) poissons d'eau profonde; (3) poissons vivant entre deux eaux; (4) poissons des îles du centre-sud; (5) poissons des îles Reine-Élisabeth; (6) poissons en hiver. Un manuel sur les poissons du Canada Arctique est nécessaire.

The ichthyological collections in the National Museum of Natural Sciences (NMNS) provide an important resource for ichthyological, fisheries, and environmental studies. Over 1,737 stations and 58,336 specimens of 95 of the 137 known fish species are represented in these Arctic Canadian collections, many from the Canadian Arctic Islands. Information on these specimens (including ecological and geographical data) can be selected, sorted, listed, summarized and mapped from our computer database. Study of these data and literature sources (McAllister and Steigerwald 1986) show deficiencies as far as the Canadian Arctic Islands are concerned.

Parts of the Arctic Archipelago ichthyofauna are poorly sampled, and the following should be given high priority in field work: (1) collect specimens of the 42 species not represented in the national collections; (2) collect deepwater fish fauna, especially in the Canadian sector between the North Pole and the Arctic Archipelago; (3) collect midwater fishes; (4) collect in the south-central Arctic Archipelago; (5) collect in the Queen Elizabeth Islands; (6) make winter collections. The improved sampling would yield reliable distribution maps useful for a number of purposes, and would provide the samples needed for research to produce a book on Arctic fishes. In addition, field research (Figure 1) is one means of demonstrating sovereignty.

---

[1] Zoology Division, National Museum of National Sciences, Ottawa, Ontario K1P 6P4

A volume on the fishes of Arctic Canada is urgently needed. The groundwork for such a book has been laid by publication of maps of existing species records (Hunter *et al.* 1984) (Figures 2-4); a list of Inuktitut, French, English and scientific names (McAllister *et al.* 1987; McAllister, in press); and a bibliography on Arctic fishes (McAllister and Steigerwald 1986). Now the NMNS needs resources to complete this project. The book would serve in the development and management of commercial, sustenance and sport fisheries, serve the needs of environmental-impact studies, and provide data for ecologists and biogeographers. Adequate life history studies are available for only 10% of Arctic marine fish species; behaviour is almost unknown. This research should involve Arctic native people. The Arctic coast of Canada is our longest,yet least known, coastline and deserves the highest priority.

REFERENCES

Hunter, J.G., S.T. Leach, D.E. McAllister, and M.B. Steigerwald. 1984. A distributional atlas of records of the marine fishes of Arctic Canada in the National Museums of Canada and Arctic Biological Station. Syllogeus 52:1-35.

McAllister, D.E. (in press). List of fishes of Canada. Syllogeus 63:1-300.

McAllister, D.E., V. Legendre, and J.C. Hunter. 1987. Liste des noms inuktitut (equimaux), français, anglais et scientifiques des poissons marins du Canada arctique/List of Inuktitut (Eskimo), French, English and scientific names of marine fishes of Arctic Canada. Report manuscrit canadien des sciences halieutiques et aquatiques No. 1932:1-106.

McAllister, D.E. and M.B. Steigerwald. 1986. Bibliography of the marine fishes of Arctic Canada, 1771-1985. Canadian Manuscript Report of Fisheries of Aquatic Sciences No. 1909:1-108.

Illustrated by Brenda Carter

FIGURE 1: Don McAllister preparing for underwater fish studies involving diving in shoreleads. Intrepid Inlet, Prince Patrick Island, 1972.

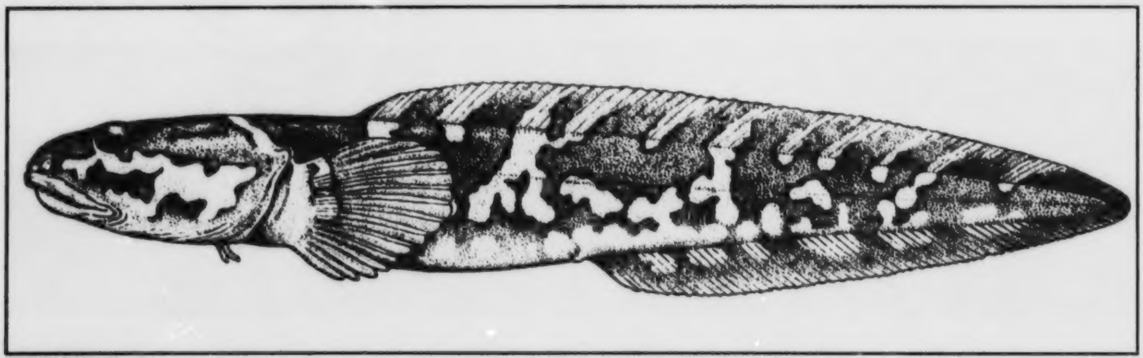


FIGURE 2: Saddled eelpout (Lycodes mucosus; male, total length 210 mm). A typical fish of the Canadian Arctic Islands.

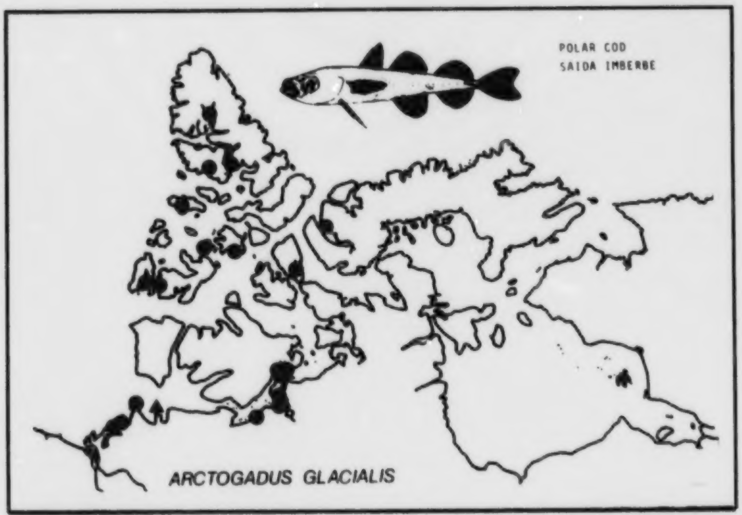

POLAR COD
SAIDA IMBERBE
ARCTOGADUS GLACIALIS

FIGURE 3: Recorded distribution of the polar cod (Arctogadus glacialis), a species common in the Arctic Islands. Dots represent specimens in the National Museum of Natural Science fish collection; triangles represent specimens in the Arctic Biological Station (Fisheries and Oceans Canada) collection (Hunter et al. 1984).

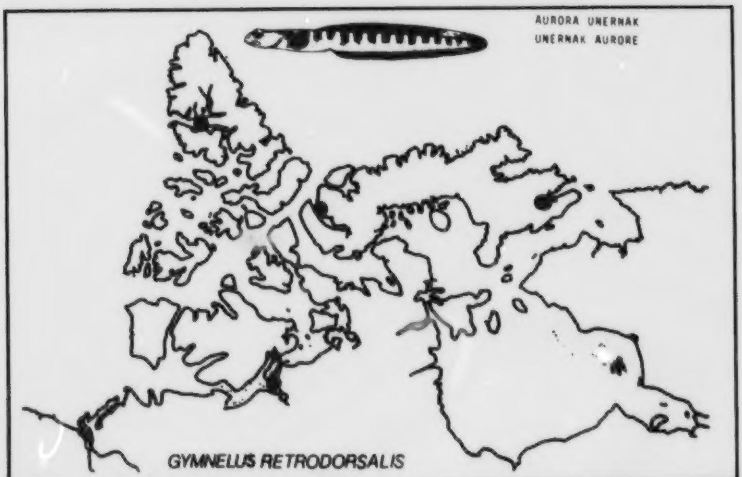

AURORA UNERNAK
UNERNAK AURORE
GYMNELUS RETRODORSALIS

FIGURE 4: Recorded distribution of another widespread fish in the Arctic Islands, the aurora unernak (Gymnelus retrodorsalis). See Figure 3 for explanation of symbols.

AVIAN ZOOGEOGRAPHY IN THE CANADIAN ARCTIC ISLANDS

Henri Ouellet[1]

Abstract: The current knowledge of bird distribution in the Canadian Arctic Islands is based on more than 200 years of exploration and field studies. This vast database available mainly, but not exclusively, from the literature, constitutes a solid but incomplete source of information upon which general distribution patterns can be generated for a number of species. However, many islands have not been surveyed yet by ornithologists. Consequently little is known about the precise distribution of many species, particularly among the small passerines and the shorebirds. Similarly, specimens are insufficient to allow the delimitation of breeding ranges of several species with populations originating in the Palearctic Region. So it is difficult to make significant progress in the analysis of geographic variation and of the origins and evolution of the bird fauna. These areas, and the species which require special attention from ornithologists and naturalists, are identified. New information is essential for comprehensive studies on the evolution and zoogeography of the bird fauna of the Canadian Arctic.

Résumé: L'état des connaissances actuelles de la répartition des oiseaux dans les îles de l'Arctique canadien est fondé sur plus de deux cents ans d'exploration et d'études de terrain. Cette vaste accumulation de données, disponible surtout dans la littérature, forme une source d'information fiable, mais souvent incomplète lorsqu'il s'agit de déterminer les aires de répartition de plusieurs espèces. En effet, plusieurs îles n'ont pas encore été inventoriées par des ornithologistes. Conséquemment, la répartition de plusieurs espèces, notamment des petits passereaux et des limicoles, n'est connue que d'une façon fragmentaire. De même, il existe dans les collections peu ou pas de spécimens provenant des certaines îles qui pourraient permettre de délimiter l'aire de nidification des espèces originaires de la Région Paléarctique. Ces lacunes ralentissent considérablement les progrès dans les études de la variation géographique ou encore de l'origine et de l'évolution de la faune aviaire des régions arctiques. Les régions qui requièrent une attention particulière de la part des ornithologistes et des naturalistes sont identifiées. Il est donc primordial de combler ces lacunes afin d'entreprendre des études plus détaillées sur l'évolution et la zoogéographie des oiseaux de l'Arctique canadien.

INTRODUCTION

Bird distribution in the Canadian Arctic has remained poorly known for a long time - as indicated by the ornithological and natural history works published during the eighteenth (Hearn 1795; Latham 1781-1785; Pennant 1785) and nineteenth centuries (Chamberlain 1887; Forster 1882; Fielden 1877; Fox and James 1894; Kumlien 1879; MacFarlane 1891; Payne 1887; Rae 1888; Richardson 1829-1837; Swainson 1836-1837; Swainson and Richardson 1831; Turner 1885, 1886; Vieillot 1807; Wilson 1808-1814). In the early part of the twentieth century the situation improved when John and James Macoun published their "Catalogue of Canadian Birds" (1909). They summarized and incorporated most of the known information about Canadian birds, including the little that was available about the avifauna of the Arctic. However, the knowledge of distribution of arctic birds in Canada was at that time very fragmentary. Bird species occurring in the vast regions north of treeline had not been surveyed in any detail. The breeding ranges remained very approximate and were restricted mainly to those areas that had been visited by the early explorers and naturalists. No systematic and comprehensive survey of the birds had yet been undertaken anywhere in that vast area of Canada.

---

[1] Zoology Division, National Museum of Natural Sciences, Ottawa, Ontario K1P 6P4

Exploratory surveys were undertaken at the turn of the twentieth century by E.A. Preble (1902, 1908) and others, which provided much needed new information. In the following, years plans for the Canadian Arctic Expedition (1913-1918) led one to expect exciting results about bird distribution from the immense unknown areas to be surveyed. Information on bird distribution and specimens gathered by the Arctic Expedition did not meet expectations primarily because the results were not generally available and were not published for many years after the return of the expedition (Anderson 1937). Following the Canadian Arctic Expedition other expeditions took place until the late 1930s, contributing to a more precise but still preliminary knowledge of bird distribution in the Canadian Arctic (Bray 1943; Gross 1937; Horring *et al.* 1937; Low 1906; Sutton 1929, 1931, 1932; Soper 1946A; Schaanning 1933; for other sources see References). Little ornithological activity took place during the Second World War, but many arctic areas were systematically explored soon after, and new data on avian distribution and ecology were obtained, contributing at least to a general overview of distribution patterns for most of the species known to occur in Canada.

Recently, particularly since the mid-1950s, many articles and papers have been published (see References), and the distribution information has been summarized in both editions of "The Birds of Canada" (Godfrey 1966, 1986). At present, the bird fauna of the Canadian Arctic, including that of most of the islands, is known at least in its broad distributional features.

PHYSIOGRAPHY

The Canadian Arctic, including the Arctic Islands, extends north of treeline to the northern extremity of Ellesmere Island (Anonymous 1985). The total area of the Canadian Arctic Islands, including Boothia and Melville peninsulas, covers 20% of Canada's territory (Table 1). Relief of the entire region is relatively gentle and remains generally under 2,000 m except for small areas on Ellesmere, Devon and Baffin islands which nevertheless lie below 2,500 m (Anonymous 1985). The entire area is included in a continuous

TABLE 1: RELATIVE AREA OF VARIOUS TERRITORIES AND ISLANDS NORTH OF TREELINE CONSIDERED TO BE IN THE ARCTIC ZONE.

REGION	AREA (km^2)
District of Franklin (including Melville and Boothia peninsulas)	1,403,134
Melville Peninsula	40,000
Boothia Peninsula	32,000
Queen Elizabeth Islands	425,000
Southampton Island	16,114
Coats Island	5,499
Mansel Island	5,375
Ottawa Islands	3,200
Belcher Islands	13,000
District of Keewatin	565,809
District of Mackenzie	1,277,447
Total area of Canadian Arctic Islands including Melville and Boothia peninsulas	1,446,322

permafrost zone with restricted ice caps and glaciers on Axel Heiberg, Ellesmere, and Baffin islands (Anonymous 1985). All the islands were glaciated and deglaciation started generally some 13,000 years ago on the western islands, but only about 10,000 years ago, or more recently, on most of the other islands (Anonymous; 1985).

The vegetation of this region is of three main types: (1) arctic tundra with low shrub; (2) rocky arctic tundra with lichens; (3) barren rocky arctic tundra (Anonymous 1985; see Bliss, and Edlund, this volume). The mean precipitation in June and July is low - under 5.1 cm (Anonymous 1985, see Mackay, this volume).

The Arctic Islands are part of the Arctic Biome (Aldrich 1967) with its characteristic climate, plants, and animals. With Greenland they belong to the Nearctic Zoogeographical Region (Wallace 1876) - an important part of the Holarctic Region.

THE BIRD FAUNA OF THE ARCTIC BIOME OF CANADA

A total of 103 bird species is given for the Arctic Zone as recognized by Salomonsen (1972), whereas Johansen (1960) lists only 80 species for approximately the same area. The definition of the "Arctic Zone" of these two authors is different because Salomonsen included several elements that could be classified as "subarctic". Considering these conflicting views in qualifying the Arctic Zone of Canada, it seems best to define it for the purposes of this work as the tundra area north of treeline. This zone thus corresponds to Aldrich's (1967) "Arctic Biome".

Using these limits and confining the species count to the Arctic Islands (Table 1), but including the Hudson Bay islands as well as Melville and Boothia peninsulas, I arrive at a total of 64 species, counting only those species known to breed or have bred within the area. Vagrants, accidentals, and irregular visitors have been excluded. Table 2 summarizes the 18 families and 64 species known to breed in the Canadian Arctic Islands. To have a clear understanding of the situation in each group, it seems appropriate to review critically each family separately in the light of the information currently available.

Gaviidae

Of the five species of this panboreal family (Mayr 1946, 1976), four are known to breed in the Arctic Islands. Among these, only one can be considered an authentic arctic species, the Red-throated Loon (*Gavia stellata*) - primarily on the basis that its breeding range extends mainly from treeline to the northern extremity of Ellesmere Island (Godfrey 1986; Figure 1A)). The others have a more southern range and their breeding distribution extends barely to the southern part of the Arctic Islands.

Procellariidae

This large family, which has a world-wide oceanic distribution, is represented in the Arctic Islands by a single species, the circumpolar Northern Fulmar (*Fulmarus glacialis*). It breeds in a number of large colonies primarily in the northeastern Arctic Islands, although it has recently extended its breeding range southward in Newfoundland and on the Labrador coast (Godfrey 1986; Brown *et al.* 1975). The Canadian breeding population is

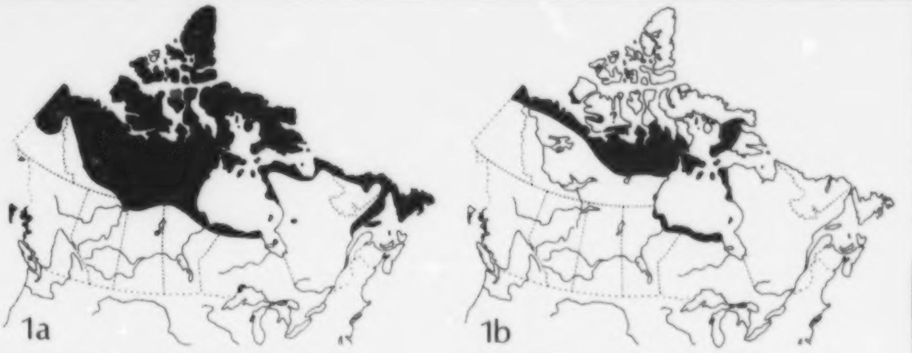
TABLE 2: FAMILIES AND SPECIES OF BREEDING BIRDS RECORDED ON THE CANADIAN ARCTIC ISLANDS. FOR COMPARATIVE PURPOSES THE NUMBER OF SPECIES ARE GIVEN FOR THE ARCTIC ISLANDS AND THE PALEARCTIC REGION, AS WELL AS THE REGIONS OF ORIGIN OF THE TAXA.

FAMILY	NUMBER OF SPECIES IN HOLARCTIC REGION^{1}	NUMBER OF SPECIES ON ARCTIC ISLANDS^{2}	REGION^{3}	SPECIES
1. Gaviidae	5	4	H	1. *Gavia stellata*
			N-H	2. *Gavia pacifica*
			N-H	3. *Gavia immer*
			N	4. *Gavia adamsii*
2. Procellariidae	1	1	H	1. *Fulmarus glacialis*
3. Anatidae	22	12	N	1. *Cygnus columbianus*
			N	2. *Anser albifrons*
			N-H	3. *Chen caerulescens*
			N	4. *Chen rossii*
			H	5. *Branta bernicla*
			N	6. *Branta canadensis*
			H	7. *Anas acuta*
			H	8. *Somateria mollissima*
			H	9. *Somateria spectabilis*
			H	10. *Histrionicus histrionicus*
			H	11. *Clangula hyemalis*
			H	12. *Mergus serrator*
4. Accipitridae	2	1	H	1. *Buteo lagopus*
5. Falconidae	2	2	H	1. *Falco peregrinus*
			H	2. *Falco rusticolus*
6. Phasianidae	2	2	H	1. *Lagopus lagopus*
			H	2. *Lagopus rusticolus*
7. Gruidae	1	1	N-H	1. *Grus canadensis*
8. Charadriidae	5	4	H	1. *Pluvialis squatarola*
			N	2. *Pluvialis dominica*
			P	3. *Charadrius hiaticula*
			N	4. *Charadrius semipalmatus*
9. Scolopacidae	27	14	H	1. *Arenaria interpres*
			H	2. *Calidris canutus*
			H	3. *Calidris alba*
			N	4. *Calidris pusilla*
			N	5. *Calidris minutilla*
			N	6. *Calidris fuscicollis*
			N	7. *Calidris bairdii*
			N	8. *Calidris melanotos*

TABLE 2: (cont'd)

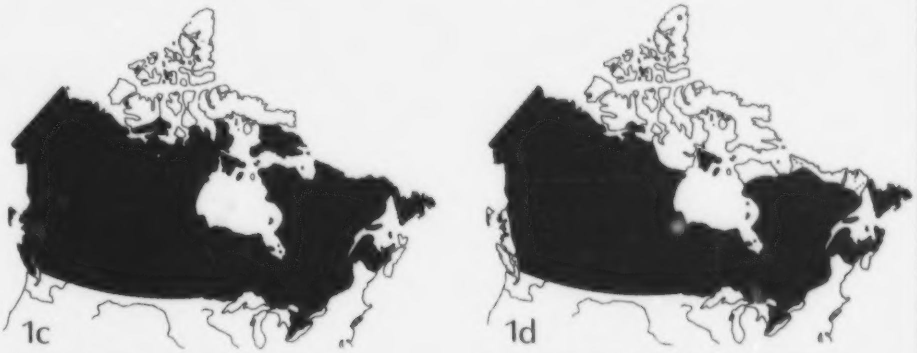
FAMILY	NUMBER OF SPECIES IN HOLARCTIC REGION[1]	NUMBER OF SPECIES ON ARCTIC ISLANDS[2]	REGION[3]	SPECIES
9. Scolopacidae (cont'd)			H	9. *Calidris maritima*
			H	10. *Calidris alpina*
			N	11. *Calidris himantopus*
			N	12. *Tryngites subruficollis*
			H	13. *Phalaropus lobatus*
			H	14. *Phalaropus fulicaria*
10. Laridae	12	11	H	1. *Stercorarius pomarinus*
			H	2. *Stercorarius parasiticus*
			H	3. *Stercorarius longicaudus*
			H	4. *Larus argentatus*
			H	5. *Larus glaucoides (thayeri)*
			H	6. *Larus hyperboreus*
			H	7. *Rissa tridactyla*
			H	8. *Rhodostethia rosea*
			H	9. *Xema sabini*
			H	10. *Pagophila eburnea*
			H	11. *Sterna paradisaea*
11. Alcidae	11	3	P	1. *Alle alle*
			H	2. *Uria lomvia*
			H	3. *Cepphus grylle*
12. Strigidae	2	1	H	1. *Nyctea scandiaca*
PASSERIFORMES				
13. Alaudidae	1	1	H	1. *Eremophila alpestris*
14. Corvidae	1	1	H	1. *Corvus corax*
15. Muscicapidae	1	1	P	1. *Oenanthe oenanthe*
16. Motacillidae	3	1	H	1. *Anthus spinoletta*
17. Emberizidae	3	2	H	1. *Calcarius lapponicus*
			H	2. *Plectrophenax nivalis*
18. Fringillidae	2	2	H	1. *Carduelis flammea*
			H	2. *Carduelis hornemanni*
TOTAL	103	64		

[1] Based on Salomonsen (1972).
[2] Based on various published and unpublished records, and on Godfrey (1986).
[3] N = Nearctic, H = Holarctic, P = Palearctic.



Breeding Distribution of Red-throated Loon

Breeding Distribution of Tundra Swan



Breeding Distribution of Canada Goose

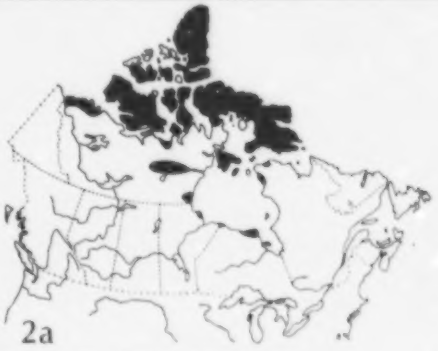
Breeding Distribution of Northern Pintail

FIGURE 1: Breeding distribution in Canada of selected bird species. Originals from Godfrey (1986) have sometimes been modified in the light of more recent information.

subspecifically different (*F. g. minor*) from the populations of the eastern and western Palaearctic (*F. g. glacialis, F. g. rodgersii*).

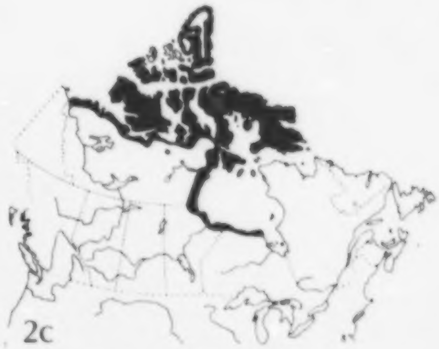
Anatidae

This large cosmopolitan family of 147 species (Bock and Farrand 1980) is represented by only 12 species in the Arctic Islands. Most of them, like the Tundra Swan (*Cygnus columbianus*) (Figure 1B), Greater White-fronted Goose (*Anser albifrons*), Ross's Goose (*Chen rossii*), Canada Goose (*Branta canadensis*) (Figure 1C), Northern Pintail (*Anas acuta*) (Figure 1D), Harlequin Duck (*Histrionicus histrionicus*), and Red-breasted Merganser (*Mergus serrator*), occur only on the southern Arctic Islands. Other species are more widespread and are found almost throughout the islands, namely: Snow Goose (*Chen caerulescens*) (Figure 2A), Brant (*Branta bernicla*) (Figure 2B), Common Eider (*Somateria mollissima*), King Eider (*Somateria spectabilis*) (Figure 2C), and Oldsquaw (*Clangula hyemalis*) (Figure 2D).



Breeding Distribution of Snow Goose

Breeding Distribution of Brant



Breeding Distribution of King Eider

Breeding Distribution of Oldsquaw

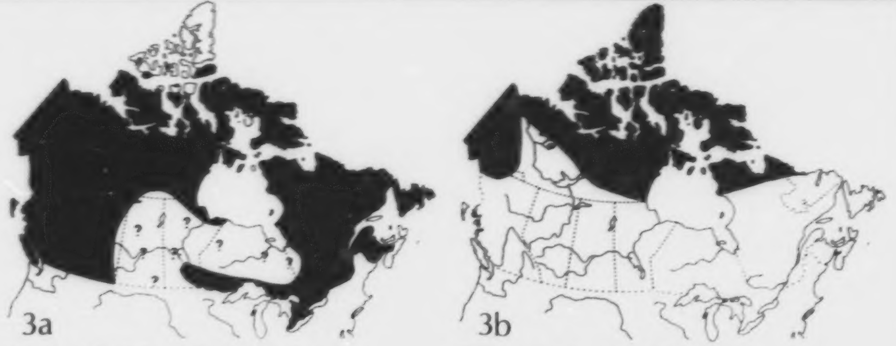
FIGURE 2: Breeding distribution in Canada of selected bird species. Originals from Godfrey (1986) have sometimes been modified in the light of more recent information.

Accipitridae

The cyclic Rough-legged Hawk (*Buteo lagopus*) is the sole representative of this large family with a nearly world-wide distribution. Another northern member of the family, the White-tailed Eagle (*Haliaetus albicilla*) breeds from southern Greenland to eastern Siberia but has not entered North America, although its range is expanding in Greenland (Salomonsen 1979).

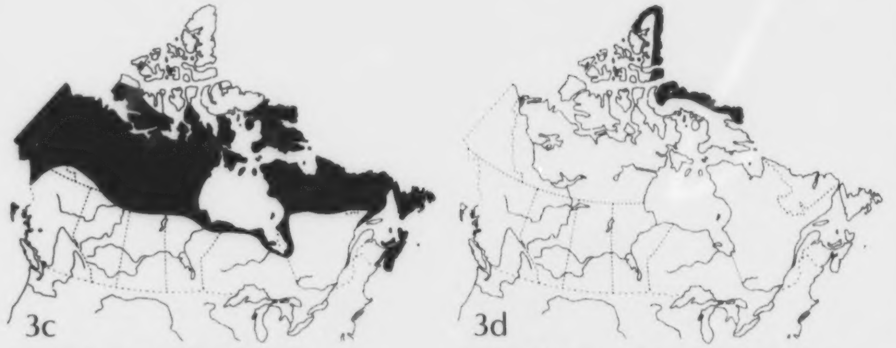
Falconidae

Only two species of this world-wide family occur in the Arctic Islands: the Peregrine Falcon (*Falco peregrinus*) restricted to the southern islands (Figure 3A) and the Gyrfalcon (*Falco rusticolus*) from treeline to northern Ellesmere Island (Figure 3B). Both birds have



Breeding Distribution of Peregrine Falcon

Breeding Distribution of Gyrfalcon



Breeding Distribution of Semipalmated Plover

Breeding Distribution of Common Ringed Plover

FIGURE 3: Breeding distribution in Canada of selected bird species. Originals from Godfrey (1986) have sometimes been modified in the light of more recent information.

diverged from the Palearctic populations to some extent, and subspecies can be recognized in the Arctic Zone of Canada (Todd and Friedmann 1947; White 1968).

Phasianidae

The subfamily Tetraoninae is widespread in Europe, Asia, and North America, but has only two representatives in the Arctic Islands. The Willow Ptarmigan (*Lagopus lagopus*) has a more southerly distribution than its congener the Rock Ptarmigan (*Lagopus mutus*), which ranges from treeline and Newfoundland to northern Ellesmere Island. Several subspecies, different from the Palearctic forms, have been recognized throughout their breeding ranges in Canada.

Gruidae

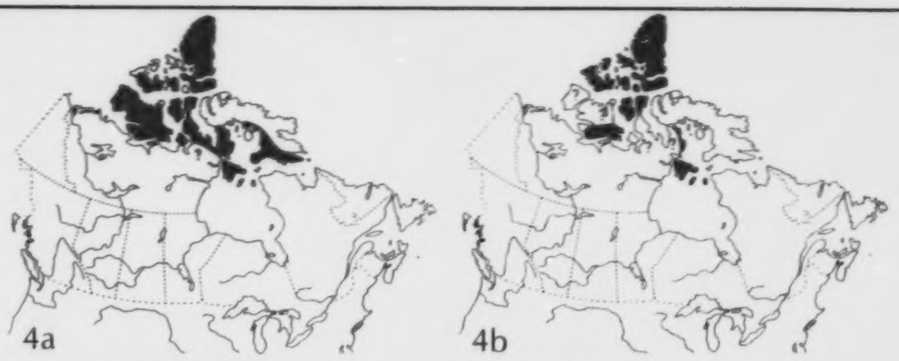
The Sandhill Crane (*Grus canadensis*) occurs in the southern part of the Arctic Archipelago (Banks, Victoria, and Baffin islands) and in the extreme southeastern part of Devon Island. The Arctic Islands population is subspecifically different from other southern populations.

Charadriidae

This small world-wide family, with five species in the circumpolar regions, is represented by four species in the Arctic Islands. The Black-bellied Plover (*Pluvialis squatarola*), Lesser Golden Plover (*Pluvialis dominica*), and Semipalmated Plover (*Charadrius semipalmatus*) (Figure 3C), occupy the southern islands, whereas the Common Ringed Plover (*Charadrius hiaticula*) (Figure 3D), apparently a recent immigrant from the Old World, breeds on the eastern fringe of the northernmost eastern islands. Its range overlaps that of its North American congener on Baffin Island (Smith 1969), but the area of sympatry in the two species has yet to be defined precisely.

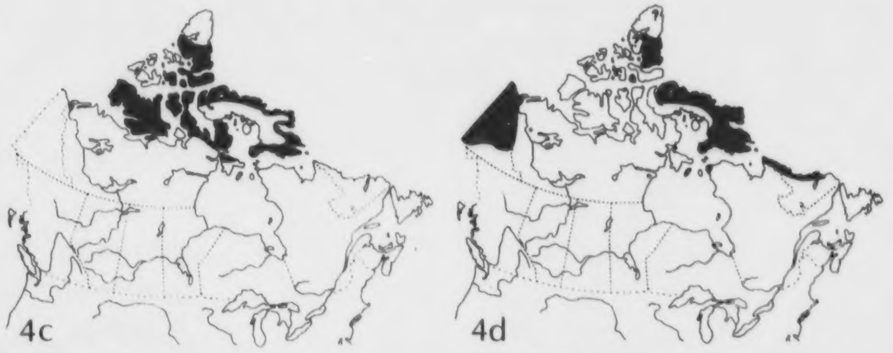
Scolopacidae

This highly diverse world-wide family has 14 representatives in the Arctic Zone of North America, some of which occur only in the Canadian Arctic Islands and in Alaska. But some species, such as the Least Sandpiper (*Calidris minutilla*) and Dunlin (*Calidris alpina*), have a breeding range restricted to the southern islands, whereas others reach eastern Siberia. The other species breed virtually on all the islands to the northern tip of Ellesmere Island, although their distribution can be very patchy in parts of their ranges. Species such as the Ruddy Turnstone (*Arenaria interpres*) (Figure 4A) and Red Knot (*Calidris canutus*) (Figure 4B), are composed of two distinct populations. The northernmost belongs to the Old World subspecies and migrates to and from the Old World (see Morrison and Davidson, this volume), whereas the more southern one migrates to and from South America during the non-breeding season. The ranges of these subspecies can only be approximated in the light of the data currently available. It is important to obtain additional material to determine the extent to which the ranges of these subspecies overlap in the Arctic Islands.



Breeding Distribution of Ruddy Turnstone

Breeding Distribution of Red Knot



Breeding Distribution of Iceland Gull

Breeding Distribution of Northern Wheatear

FIGURE 4: **Breeding distribution in Canada of selected bird species. Originals from Godfrey (1986) have sometimes been modified in the light of more recent information.**

Laridae

This cosmopolitan family is represented in the Arctic Islands by 11 species, which occur also in the other circumpolar regions although their distribution can form a complex mosaic. Of the three jaeger (*Stercorarius*) species, only one reaches the northern extremity of Ellesmere Island. The others occur in the central portion of the Arctic Zone. The Herring Gull (*Larus argentatus*) reaches only the southern islands and appears to be replaced farther north by the Iceland Gull (*Larus glaucoides*) (Figure 4C) and the Glaucous Gull (*Larus hyperboreus*). The distribution of *Larus glaucoides* is complex and only known in a cursory manner - at least as far as its various populations are concerned. The Black-legged Kittiwake (*Rissa tridactyla*), although not confined to the Arctic Zone, maintains large colonies on some of the eastern Arctic Islands, and is expending in the southern part of its range. The rare Ross's Gull (*Rodostethia rosea*) and Ivory Gull (*Pagophila eburnea*) (Thomas and

MacDonald 1987; Frisch 1983; Reed and Dupuis 1983; Renaud and McLaren 1982) have a patchy distribution, and their precise ranges are still incompletely known.

Alcidae

Of the 11 species recorded in the Arctic Zone of the Holarctic Region, only two breed regularly in the Arctic Islands of Canada, the Thick-billed Murre (*Uria aalge*) and Black Guillemot (*Cepphus grylle*). Neither species reaches the northern extremity of Ellesmere Island; they are found mainly along the eastern periphery of the archipelago. A third species, the Dovekie (*Alle alle*) has recently been reported on Baffin Island (Finley and Evans 1984) and may represent a recent range extension from Greenland.

Strigidae

Only the circumpolar Snowy Owl (*Nyctea scandiaca*) is known to occur on all the Arctic Islands. The Short-eared Owl (*Asio flammeus*) may breed on the southern islands but this requires confirmation.

Alaudidae

The cosmopolitan Horned Lark (*Eremophila alpestris*), with one recognized subspecies, is known to breed on all the islands south of Ellesmere Island.

Corvidae

In this cosmopolitan and resourceful family, only the Common Raven (*Corvus corax*) occupies the Arctic Islands to the latitude of central Ellesmere Island. It seems absent from Coats and Mansel islands as a breeding bird but detailed field observations are still required for those islands, although nesting sites may be very rare on Mansel Island.

Muscicapidae

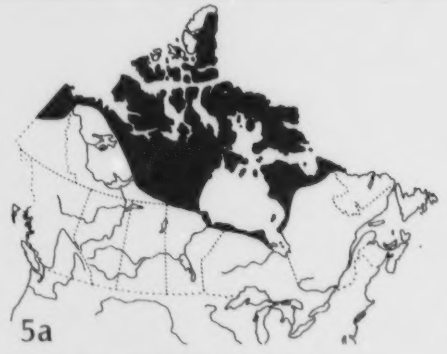
This very large Old World family (1,427 species; Bock and Farrand 1980) is poorly represented in the Arctic Zone by a single circumpolar species, the Northern Wheatear (*Oenanthe oenanthe*). In Canada, there are two distinct subspecies (Figure 4D) (Godfrey 1986; Boothroyd 1984; Sutton and Parmelee 1954). This bird is probably a recent immigrant to North America.

Motacillidae

A single representative of this small cosmopolitan family can be found on the southern islands of the archipelago: the Water Pipit (*Anthus spinoletta*). It is generally widespread where it occurs.

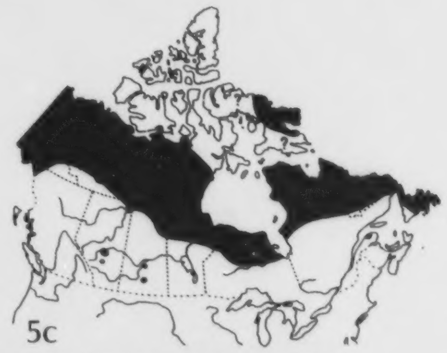
Emberizidae

This large family of Nearctic origin (Mayr 1946, 1976) is represented in the Arctic Islands by two members of the subfamily Emberizinae: the Lapland Longspur (*Calcarius lapponicus*) (Figure 5A) and Snow Bunting (*Plectrophenax nivalis*) (Figure 5B). They are found on all the islands, although they have a patchy distribution in certain sectors of the archipelago.



Breeding Distribution of Lapland Longspur

Breeding Distribution of Snow Bunting



Breeding Distribution of Common Redpoll

Breeding Distribution of Hoary Redpoll

FIGURE 5: Breeding distribution in Canada of selected bird species. Originals from Godfrey (1986) have sometimes been modified in the light of more recent information.

Fringillidae

Two members of the subfamily Carduelinae represent this family of Palearctic origin: the Common Redpoll (*Carduelis flammea*) (Figure 5C) and Hoary Redpoll (*Carduelis hornemanni*) (Figure 5D). Both species display considerable geographic variation, and their relationships within the entire Holarctic Region are unclear. The status of these two species is currently under review and requires additional study.

Summary

This cursory taxonomic review provides basic information about the diversity and origin of the bird fauna of the Canadian Arctic Islands. It also indicates the need for detailed distribution studies for many species in northern Canada to determine their origin, precise taxonomic status, and range alterations relative to historical events, climatic fluctuations, and ecological variations.

SPECIES DIVERSITY

Latitudinal gradients in species diversity have been discussed at some length (Pianka 1966), but no study has been undertaken concerning this aspect of bird distribution in the Canadian Arctic. An analysis of species densities in North American birds (Cook 1969) presented interesting data about breeding birds on the continent, but the information given for the Canadian Arctic is incomplete, or inadequate in some cases. A thorough analysis is warranted, even if the information on hand is still incomplete. As an example, I have plotted for six arctic and subarctic localities the number of known breeding species. The results (Figure 6) indicate a statistically-significant correlation between latitude and the number of breeding species ($r = -0.9531$). As expected, the number of breeding species diminishes significantly northward. Although more data are required, a preliminary analysis of species diversity in the Arctic Islands is possible when all currently available data have been compiled. This would reveal interesting, if not spectacular, facts about avian distribution patterns in Arctic Canada.

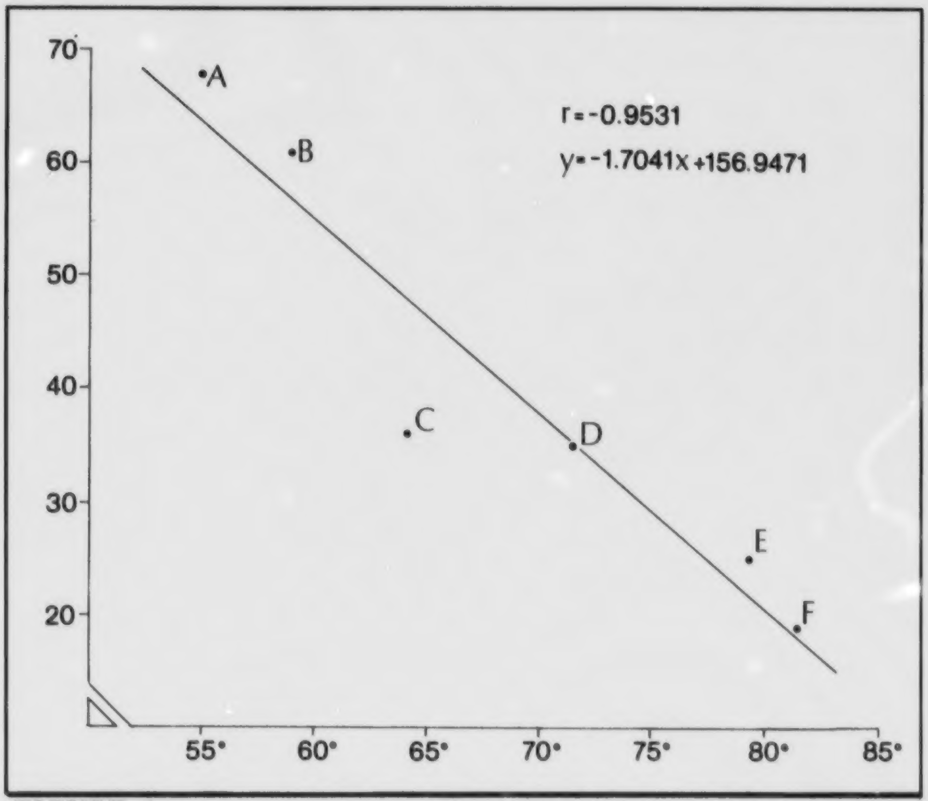


FIGURE 6: **Linear regression between the total number of breeding species against latitude for selected localities, as follows: (A) Schefferville, (B) Kuujjuak (Fort Chimo), (C) Iqaluit (Frobisher Bay), (D) Pond Inlet, (E) Alexandra Fiord, and (F) Alert.**

THE ORIGIN OF THE BIRD FAUNA

My review of the bird fauna of the Arctic Islands shows that not one of the families considered to be of Neotropical origin (Mayr 1946, 1976) has reached the Arctic Zone or the southernmost islands of the archipelago. This is not surprising considering that most members of those families or subfamilies (e.g. Trochilidae, Tyrannidae, Vireonidae, Parulinae, and Thraupinae) are forest or woodland species. However, most species of two other subfamilies (Cardinalinae and Icterinae), birds of open or semi-open areas, are also absent from the Arctic Zone.

The immigrants from the Palearctic Region are numerous, and are still colonizing the archipelago. As an example, the Northern Wheatear (*Oenanthe oenanthe*) is probably a recent immigrant on both sides of the North American continent (Figure 4D). The western Palearctic subspecies *O. o. leucorhoa* is colonizing the eastern Arctic Islands and continues to expand, as indicated by data collected since the turn of the century. On the western side of the continent, the more eastern nominal Palearctic subspecies *O. o. oenanthe* is colonizing North America via Alaska, the Yukon, and the northwestern part of the District of Mackenzie. Although it has not yet reached the western Arctic Islands, it is only a question of time before it becomes established on some of them. In a less spectacular fashion, subspecies from the western Palearctic have colonized at least the eastern Arctic Islands, and appear to be still expanding (e.g. the Ruddy Turnstone (*Arenaria interpres interpres*) (Figure 4A) and Red Knot (*Calidris canutus canutus*) (Figure 4B). Similarly, although little information is available at present, it is predictable that an eastern Palearctic population, possibly originating in Siberia may colonize the western islands of the Archipelago, if present climatic conditions remain relatively stable.

DISCUSSION AND CONCLUSIONS

Information currently available indicates that the bird fauna of the Canadian Arctic Islands originates mainly from two centres outside North America: (1) the western European Arctic; and (2) the eastern Palaearctic boreal region, particularly Siberia. This agrees with the results of earlier studies (Mayr 1946, 1976), and shows a small diversity and much movement among populations, which have given rise to colonization by certain members of the Pan-boreal Element (Mayr 1946, 1976) within the Gaviidae, Phalaropinae, and Alcidae. On the other hand, the Gruidae, Strigidae, Corvidae, Muscicapidae, Motacillidae, and Carduelinae constitute the Old World Element (Mayr 1946, 1976) of the northern Nearctic avifauna. The North American Element is more restricted and comprises the Phasianidae (Tetraoninae) and the Emberizidae (Emberizinae) (Mayr 1946, 1976). No species considered to belong to the Pan-American Element or the South American Element (Mayr 1946, 1976) have reached and colonized the Arctic Islands. Range shifts related to climatic fluctuations have undoubtedly occurred in the Arctic Islands, but little information is available at present. Data collected regularly for taxonomic, systematic, distribution, and ecological studies over wide areas in the Arctic Zone would permit a better understanding of colonizing populations - particularly such aspects as genetics, ecology, and variation at the intra and interspecific levels (Parsons 1982). Furthermore, such data would provide insight into the mechanisms of invasions (Mooney and Drake 1986) and possibly extinctions as well (Martin and Klein 1984).

ACKNOWLEDGEMENTS

I wish to extend my sincere thanks to Michel Gosselin for assistance and for preparing the figures.

REFERENCES (SELECTED BIOGRAPHY)

Abraham, D.M. and C.D. Ankney. 1984. Partitioning of foraging habitat by Sabine's Gulls and Arctic Terns. Wilson Bulletin 96(2):161-172.

Abraham, K.F. and C.D. Ankney. 1986. Summer birds of East Bay, Southampton Island, Northwest Territories. Canadian Field-Naturalist 100(2):180-185.

Abraham, K.F., C.D. Ankney, and H. Boyd. 1983. Assortative mating by Brant. Auk 100(1):201-203.

Aldrich, J.W. 1967. Taxonomy, distribution and present status. Chapter 2. In: The Wild Turkey and Its Management. Edited by: O.H. Hewitt. Wildlife Society, Washington, D.C. pp. 1-589.

Allen, E.G. 1951. The history of American ornithology before Audubon. Transactions of the American Philosophical Society 41:386-591.

Allen, J.A. 1908. Pennant's 'Indian zoology'. Bulletin of the American Museum of Natural History 24:111-116.

Anderson, R.M. 1913. Report on the natural history collections of the expedition. Birds. In: V. Stefansson - My Life with the Eskimo. The Macmillan Company, New York. pp. 456-494.

______. 1937. Mammals and birds of the western Arctic district, North-west Territories, Canada. In: Canada's Western Northland. Lands, Parks and Forests Branch. Ottawa. pp. 97-122.

Anonymous. 1985. The national atlas of Canada; 5th Edition. Energy, Mines and Resources Canada, Ottawa.

Austin, O.L., Jr. 1932. The birds of Newfoundland and Labrador. Memoirs of the Nuttall Ornithology Club 7:1-229.

Barry, T.W. and J.N. Eisenhart. 1958. Ross' Geese nesting at Southampton Island, N.W.T., Canada. Auk 75(1):89-90.

Bee, J.W. 1958. Birds found on the Arctic Slope of northern Alaska. University of Kansas, Publication of the Museum of Natural History 10(5):163-211.

Birkhead, T.R., E. Greene, J.D. Biggins, and D.N. Nettleship. 1985. Breeding site characteristics and breeding success in Thick-billed Murres. Canadian Journal of Zoology 63(8):1880-1884.

Birkhead, T.R. and D.N. Nettleship. 1981. Reproductive biology of Thick-billed Murres (*Uria lomvia*): an inter-colony comparison. Auk 98(2):258-269.

______. 1982. The adaptative significance of egg size and laying date in Thick-billed Murres *Uria lomvia*. Ecology 63(2):300-306.

Bliss, L.C., O.W. Heal, and J.J. Moore (Editors). 1981. Tundra ecosystems: a comparative analysis. Cambridge University Press, Cambridge. pp. 1-813.

Blomqvist, S. and M. Elander. 1981. Sabine's Gull (*Xema sabini*), Ross's Gull (*Rhodostethia rosea*) and Ivory Gull (*Pagophila eburnea*). Gulls in the Arctic: a review. Arctic 34(1):122-132.

Blondel, J. 1979. Biogéographie et évolution. Collection d'écologie, no. 15. Masson, Paris. 173 pp.

______. 1986. Biogéographie évolutive. Collection d'écologie, no. 20. Masson, Paris. pp. 1-221.

Bock, W.J. and J. Farrand, Jr. 1980. The number of species and genera of recent birds: a contribution to comparative systematics. American Museum Novitates 2703:1-29.

Boothroyd, P.N. 1984. Northern Wheatears, *Oenanthe oenanthe* on Axel Heiberg and Ellesmere Islands, Northwest Territories. Canadian Field-Naturalist 98(1):48-49.

Boyd, H. and L.S. Maltby. 1979. The brant of the western Queen Elizabeth Islands, N.W.T. In: Management and Biology of Pacific Flyway Geese. Edited by: R.J. Jarvis and J.C. Bartonek. Oregon State University, Corvallis. pp. 5-21.

Boyd, H., G.E.J. Smith, and F.G. Cooch. 1982. The Lesser Snow Geese of the eastern Canadian Arctic. Canadian Wildlife Service, Occasional Paper 46:1-25.

Bray, R. 1943. Notes on the birds of Southampton Island, Baffin Island, and Melville Peninsula. Auk 60(4):504-536.

Brooks, W.S. 1915. Notes on birds from east Siberia and Arctic Alaska. Bulletin of the Museum of Comparative Zoology 59(5):361-413.

Brown, R.G.B., D.N. Nettleship, P. Germain, C.E. Tull, and T. Davis. 1975. Atlas of eastern Canadian seabirds. Canadian Wildlife Service, Ottawa. 220 pp..

Cairns, D.K. 1985. Ermine visitation to Black Guillemot colonies in northeastern Hudson Bay. Condor 87(1):144-145.

Chamberlain, M. 1887. A catalogue of Canadian birds, with notes on the distribution of the species. J.&A. McMillan. Saint John. 143 pp..

Chernov, Y.I. 1985. The living tundra. Cambridge University Press, Cambridge. 213 pp.

Cheylan, G. 1984. Les mammifères des îles de Provence et de Méditerranée occidentale: un exemple de peuplement insulaire non-équilibré? Terre et Vie 39(1):37-54.

Cook, R.E. 1969. Variation in species density of North American birds. Systematic Zoology 18(1):63-84.

Cooke, A. and C. Holland. 1978. The exploration of northern Canada: 500 to 1920, a chronology. The Arctic History Press, Toronto. 549 pp.

Coulter, R. 1981. The Joint Services Expedition to Princess Marie Bay, Ellesmere Island, 1980. Part 2 - Brief impressions. Sea Swallow 30:21-22.

Eifrig, C.W.G. 1905. Ornithological results of the Canadian "Neptune" expedition to Hudson Bay and northward, 1903-1904. Auk 22(3):232-241.

Ellis, D.V. and J. Evans. 1960. Comments on the distribution and migration of birds in Foxe Basin, Northwest Territories. Canadian Field-Naturalist 74(1):59-70.

Fielden, H.W. 1877. List of birds observed in Smith Sound and in Polar Basin during the Arctic Expedition of 1875-76. Ibis, 4th series, 1(4):401-412.

Finley, K.J. and C.R. Evans. 1984. First Canadian breeding record of the Dovekie (*Alle alle*). Arctic 37(3):288-289.

Forster, J.R. 1882. XXIX. An account of the birds sent from Hudson's Bay; with observations relative to their natural history and Latin descriptions of some of the most uncommon. Read June 18-25, 1772. Willughby Society, London. pp. 382-433.

Fox, L. and T. James, 1894. Voyages of Foxe and James. Hakluyt Society Publication 2:88-89.

Freedman, B. and J. Svoboda. 1982. Populations of breeding birds at Alexandra Fjord, Ellesmere Island, Northwest Territories, compared with other Arctic localities. Canadian Field-Naturalist 96(1):56-60.

Frisch, T. 1983. Ivory Gull colonies on the Devon Island Ice Cap, Arctic Canada. Arctic 36(4):370-371.

Gabrielson, I.N. and F.C. Lincoln. 1959. The birds of Alaska. Wildlife Management Institute. Stackpole Co., Harrisburg. 922 pp.

Gaston, A.J. 1980. Populations, movements and wintering areas of Thick-billed Murres *Uria lomvia* in eastern Canada. Canadian Wildlife Service, Progress Notes 110:1-10.

______. 1982A. Migration of juvenile Thick-billed Murres through Hudson Strait in 1980. Canadian Field-Naturalist 96(1):30-34.

______. 1982B. On the seabirds of northern Hudson Bay. Naturaliste Canadien 109:895-903.

______. 1985. The diet of Thick-billed Murre chicks in the eastern Canadian Arctic. Auk 102(4):727-734.

Gaston, A.J., G. Chapdelaine, and D.G. Noble. 1984. Phenotypic variation among Thick-billed Murres from colonies in Hudson Strait. Arctic 37(3):284-287.

Gaston, A.J. and R. Decker. 1985. Interbreeding of Thayer's Gull, *Larus thayeri*, and Kumlien's Gull, *Larus glaucoides kumlieni*, on Southampton Island, Northwest Territories. Canadian Field-Naturalist 99(2):257-259.

Gaston, A.J., R. Decker, F.G. Cooch, and A. Reed. 1986. The distribution of larger species of birds breeding on the coasts of Foxe Basin and northern Hudson Bay, Canada. Arctic 39(4):285-296.

Gaston, A.J. and D.N. Nettleship. 1981. The Thick-billed Murres of Prince Leopold Island. Canadian Wildlife Service, Monograph Series 6:1-350.

Giroux, J.F., Y. Bédard, and J. Bédard. 1984. Habitat use by the Greater Snow Geese during the brood-rearing period. Arctic 37(2):155-160.

Godfrey, W.E. 1953. Notes of Ellesmere Island birds. Canadian Field-Naturalist 67(2):89-93.

______. 1966. The birds of Canada. National Museums of Canada, Biological Series 73, Bulletin 203:1-428.

______. 1986. The birds of Canada. Revised Edition. National Museum of Natural Sciences, Ottawa. 595 pp.

Gross, A.O. 1937. Birds of the Bowdoin-MacMillan Arctic Expedition 1934. Auk 54(1):12-42.

Hearne, S. 1795. A journey from Prince of Wales Fort in Hudson's Bay to the Northern Ocean. J.W. Davis, London. 458 pp.

Holyoak, D.T. 1983. Notes on the birds of southwestern Banks Island, Northwest Territories, Canada. Bulletin of the British Ornithological Club 103(2):37-39.

Horring, R., J.R. Pfoff, K.L. Henriksen, and K. Stephenson. 1937. Report on the Fifth Thule Expedition, 1921-24. Part 2, Zoology. In: The Danish Expedition to Arctic North America in Charge of Knud Rasmussen. Copenhagen. 133 pp.

Houston, C.S. 1983. Birds first described from Hudson Bay. Canadian Field-Naturalist 97(1):95-98.

______. 1984A. Arctic ordeal. The journal of John Richardson, surgeon-naturalist with Franklin, 1820-1822. McGill-Queen's University Press, Kingston and Montreal. 348 pp.

______. 1984B. John Richardson - first naturalist in the Northwest. Beaver, autumn:10-15.

Hussell, D.J.T. and G.L. Holroyd. 1974. Birds of the Truelove Lowland and adjacent areas of northeastern Devon Island. Canadian Field-Naturalist 88(2):197-212.

Johansen, H. 1960. Die Entstehung der arktischen Vogelfauna. In: Proceedings of the XII International Ornithological Congress, 1958. Helsinki. pp. 358-362.

Johnson, S.R. and J.G. Ward. 1985. Observations of Thick-billed Murres (*Uria lomvia*) and other seabirds at Cape Parry, Amundsen Gulf, N.W.T. Arctic 38(2):112-115.

Kennedy, A.J. 1981. Snowy Owl prey on Prince of Wales Island, Northwest Territories. Naturaliste Canadien 108(2):195-197.

Kerbes, R.H. 1983. Lesser Snow Goose colonies in the western Canadian Arctic. Journal of Wildlife Management 47(2):523-526.

Kerbes, R.H., M.R. McLandress, G.E.J. Smith, G.W. Beyersbergen, and B. Godwin. 1983. Ross' Goose and Lesser Snow Goose colonies in the central Canadian Arctic. Canadian Journal of Zoology 61(1):168-173.

Kessel, B. and D.D. Gibson. 1978. Status and distribution of Alaska birds. Studies in Avian Biology 1:1-100.

Kishchinskii, A.A. 1979. Birds and the problem of the Bering land bridge between the continents. Bulletin of the Moscow Society of Naturalists 84(1):5-12.

Kumlien, L. 1879. Contribution to the natural history of Arctic America. United States National Museum, Bulletin 15:1-179.

Latham, J. 1781-1785. A general synopsis of birds. Volume I. Parts 1, 2; Volume II. Parts 1, 2: Volume III. Parts 1, 2. Leigh and Sotheby, London.

Longcore, J.R., J.D. Heyland, A. Reed, and P. Laporte. 1983. Contaminants in Greater Snow Geese and their eggs. Journal of Wildlife Management 47(4):1105-1109.

Low, A.P. 1906. Report on the Dominion Government Expedition to Hudson Bay and the Arctic Islands on board the D.G.S. *Neptune*, 1903-1904. Government of Canada, Ottawa. pp. 314-319.

MacDonald, S.D. 1954. Report on biological investigations at Mould Bay, Prince Patrick Island, N.W.T. Annual Report, National Museum of Canada 1952-53, 132:214-238.

______. 1960. Biological investigations at Isachsen, Ellef Ringnes Island, N.W.T. National Museum of Canada, Bulletin 172:90-97.

MacFarlane, R. 1891. Notes on and list of birds and eggs collected in Arctic America, 1861-1866. Proceedings of the United States National Museum 14:413-446.

Macoun, J. and J.M. Macoun. 1909. Catalogue of Canadian birds. Geological Survey of Canada, Publication 973:1-761.

Macpherson, A.J. and T.H. Manning. 1959. The birds and mammals of Adelaide Peninsula, N.W.T. National Museum of Canada, Biological Series 59, Bulletin 161:1-63.

Macpherson, A.H. and I.A. McLaren. 1959. Notes on the birds of southern Foxe Peninsula, Baffin Island, Northwest Territories. Canadian Field-Naturalist 73(1):63-81.

Maher, W.J. and D.N. Nettleship. 1968. The pintail (*Anas acuta*) breeding at latitude 82°N on Ellesmere Island, N.W.T., Canada. Auk 85(3):320-321.

Maltby, L.S. 1978. Birds of the coastal zone of Melville Island, 1973-1975. Canadian Field-Naturalist 92(1):24-29.

Manning, T.H. 1952. Birds of west James Bay coast between Long Point and Cape Jones. Canadian Field-Naturalist 66(1):1-35.

______. 1981. Birds of Twin Islands, James Bay, N.W.T., Canada. Syllogeus 30:1-50.

Manning, T.H., E.O. Hohn, and A.H. Macpherson. 1956. The birds of Banks Island. National Museum of Canada, Biological Series 48, Bulletin 143:1-144.

Manning, T.H. and A.H. Macpherson. 1961. A biological investigation of Prince of Wales Island, N.W.T. Transactions of the Royal Canadian Institute 33(2):116-239.

Martin, P.S. and R.G. Klein. (Editors). 1984. Quaternary extinctions: a prehistoric revolution. University of Arizona Press, Tucson. 892 pp.

Mayfield, H.F. 1983. Densities of breeding birds at Polar Bear Pass, Bathurst Island, Northwest Territories. Canadian Field-Naturalist 97(4):371-376.

Mayr, E. 1946. History of the North American bird fauna. Wilson Bulletin 58(1):1-68.

______. 1976. History of the North America bird fauna. In: Evolution and the Diversity of Life, Selected Essays. Edited by: E. Mayr. The Belknap Press, Cambridge, Massachusetts. pp. 565-588.

Mayr. E. and R.J. O'Hara. 1986. The biogeographic evidence supporting the Pleistocene forest refuge hypothesis. Evolution 40(1):55-67.

Mayr, E. and L.L. Short. 1970. Species taxa of North American birds, a contribution to comparative systematics. Nuttall Ornithological Club, Publication 9:1-127.

McLaren, M.A. and W.G. Alliston. 1985. Effects of snow and ice on waterfowl distribution in the central Canadian Arctic Islands. Arctic 38(1):43-52.

McLaren, M.A. and P.L. McLaren. 1984. Tundra Swans in northeastern Keewatin District, N.W.T. Wilson Bulletin 96(1):6-11.

McLaren, P.L. 1982. Spring migration and habitat use by seabirds in eastern Lancaster Sound and western Baffin Bay. Arctic 35(1):88-111.

McLaren, P.L. and M.A. McLaren. 1982. Waterfowl population in eastern Lancaster Sound and western Baffin Bay. Arctic 35(1):149-157.

McLaren, P.L. and W.E. Renaud. 1982. Seabird concentrations in late summer along the coasts of Devon and Ellesmere islands. Arctic 35:112-117.

Molau, U. 1985. Grasiskkomplexet i Sverige. Vår Fågelvärld 44:5-20.

Montgomerie, R.D., R.V. Cartar, R.L. McLaughlin, and B. Lyon. 1983. Birds of Sarcpa Lake, Melville Peninsula, Northwest Territories: breeding phenologies, densities and biogeography. Arctic 36(1):65-75.

Mooney, H.A. and J.A. Drake. (Editors). 1986. Ecology of biological invasions of North America and Hawaii. Springer-Verlag, New York, Berlin. 321 pp.

Muir, D. and D.M. Bird. 1984. Food of Gyrfalcons at a nest on Ellesmere Island. Wilson Bulletin 96(3):464-467.

Nettleship, D.N. and T.R. Birkhead. (Editors). 1985. The Atlantic Alcidae. Academic Press, New York. 574 pp.

Nystrom, B. and H. Nystrom. 1987. Biotopval och hackning hos grasiskor *Carduelis flammea* och snosiskor *C. hornemanni* i Ammarnasomradet, sodra Lappland. Vår Fågelvärld 87(3):119-128.

Orr, C.D., R.M.P. Ward, N.A. Williams, and R.G.B. Brown. 1982. Migration patterns of Red and Northern Phalaropes in southwest Davis Strait and in the northern Labrador Sea. Wilson Bulletin 94(3):303-312.

Osborne, D. 1983. Brent Geese in the Arctic. Irish Birds 2(3):303-308.

Parker, G.R. and R.K. Ross. 1973. Notes on the birds of Southampton Island, Northwest Territories. Arctic 26(2):123-129.

Parmelee, D.F. and S.D. MacDonald. 1960. The birds of west-central Ellesmere Island and adjacent areas. National Museum of Canada, Biological Series 63, Bulletin 169:1-103.

Parmelee, D.F., H.A. Stephens, and R.H. Schmidt. 1967. The birds of southeastern Victoria Island and adjacent small islands. National Museum of Canada, Bulletin 222:1-229.

Parsons, P.A. 1982. Adaptive strategies of colonizing animal species. Biological Review 57(1):117-148.

Paulson, D.R. and W.J. Erckmann. 1985. Buff-breasted Sandpipers nesting in association with Black-bellied Plovers. Condor 87(3):429-430.

Payne, F.F. 1887. Mammals and birds of Prince of Wales Sound, Hudson's Strait. Proceedings of the Canadian Institute, 3rd series 1:119-123.

Pennant, T. 1785. Arctic zoology. Volume II. Class II, Birds. Henry Hughs, London. pp. 188-586.

Pianka, E.R. 1966. Latitudinal gradients in species diversity: a review of concepts. American Naturalist 100(910):33-46.

Ploeger, P.L. 1968. Geographical differentiation in Arctic Anatidae as a result of isolation during the last glacial. Ardea 56(1):1-159.

Porsild, A.E. 1951. Bird notes from Banks and Victoria islands. Canadian Field-Naturalist 65(1):40-42.

Prach, R.W., H. Boyd, and F.G. Cooch. 1981. Polynyas and seaducks. In: Polynyas in the Canadian Arctic. Edited by: I. Stirling and H. Cleator. Canadian Wildlife Service, Occasional Paper No. 45:67-70.

Preble, E.A. 1902. A biological investigation of the Hudson Bay region. North American Fauna 22:75-131.

______. 1908. A biological investigation of the Athabasca-Mackenzie region. North American Fauna 27:1-574.

Rae, J. 1888. Notes on some of the birds and mammals of the Hudson's Bay Co's. Territories and the Arctic Coast. Canadian Record of Science 3(3):125-136.

Reed, A. and P. Dupuis. 1983. Ivory Gulls, *Pagophila eburnea*, nesting on the Brodeur Peninsula, N.W.T. Canadian Field-Naturalist 97(3):332.

Renaud, W.E., W.G. Johnston, and K.J. Finley. 1981. The avifauna of the Pond Inlet region, N.W.T. American Birds 35(2):119-129.

Renaud, W.E. and P.L. McLaren. 1982. Ivory gull (*Pagophila eburnea*) distribution in late summer and autumn in eastern Lancaster Sound and western Baffin Bay. Arctic 35:141-148.

Richardson, J. 1829-1837. Fauna boreali-americana, or the zoology of the northern parts of British America. (4 volumes). J. Murray, London.

Salomonsen, F. 1950. The birds of Greenland. Ejnar Munksgaard, Copenhagen. 607 pp.

______. 1972. Zoogeographical and ecological problems in arctic birds. In: Proceedings of the XV International Ornithological Congress, 1970. Edited by: K.H. Voous. E.J. Brill, Leiden. pp. 25-77.

______. 1979. Ornithological and ecological studies in S.W. Greenland (59° 46'-62°27'N. Lat.). Meddelelser om Grønland 204(6):1-214.

Savile,D.B.O. 1950. Bird observations at Chesterfield Inlet, Keewatin 1950. Canadian Field-Naturalist 65(4):145-157.

______. 1961. Bird and mammal observations on Ellef Ringnes Island in 1960. National Museum of Canada, Natural History Papers 9:1-6.

Schaanning, H.T.L. 1933. Birds from Arctic North America. Ornithological results of the Fram-expedition 1898-1902 and the Gjoa-expedition 1903-1907. Meddeleleser fra det Zoologiske Museum, Oslo 33:137-165.

Smith, N.G. 1969. Polymorphism in Ringed Plovers. Ibis 111(1):177-188.

Smith, T.G. 1973. The birds of the Holman region, western Victoria Island. Canadian Field-Naturalist 87(1):35-42.

______. 1981. Sharp-shinned Hawk, *Accipiter striatus* (Accipitriformes: Accipitridae), on Victoria Island, Northwest Territories. Canadian Field-Naturalist 95(3):366.

Snyder, L.L. 1957. Arctic birds of Canada. University of Toronto Press, Toronto. 310 pp.

Soper, J.D. 1928. A faunal investigation of southern Baffin Island. National Museum of Canada, Biological Series 15, Bulletin 53:1-143.

Soper, J.D. 1940. Local distribution of eastern Canadian arctic birds. Auk 57(1):13-21.

______. 1946A. Ornithological results of the Baffin Island Expeditions of 1928-1929 and 1930-1931, together with more recent records. Auk 63(1-3): 1-24, 223-239, 418-427.

______. 1946B. Supplementary data concerning the Blue Goose. Canadian Field-Naturalist 60(5):110-113.

Steadman, D.W. and P.S. Martin. 1984. Extinction of birds in the late Pleistocene of North America. Chapter 21. In: Quaternary Extinctions: A Prehistoric Revolution. Edited by: P.S. Martin and R.G. Klein. University of Arizona Press, Tucson. pp. 466-477.

Stevens, O.A. 1936. The first descriptions of North American birds. Wilson Bulletin 47(3):203-215.

Stresemann, E. 1975. Ornithology from Aristotle to the present. Harvard University Press, Cambridge, Massachusetts. 432 pp.

Sutton, G.M. 1929. Notes on a collection of birds from Mansel Island, Hudson Bay, Condor 34(1):41-43.

______. 1931. Notes on birds observed along the west coast of Hudson Bay. Condor 33(4):154-159.

______. 1932. The birds of Southampton Island. Memoir of the Carnegie Museum, Part 2, Section 2, 12:1-275.

Sutton, G.M. and D.F. Parmelee. 1954. Nesting of the Greenland Wheatear on Baffin Island. Condor 56(5):295-305.

Swainson, W. 1836-1837. On the natural history and classification of birds. Volumes 1, 2. Lardner's Cabinet Encyclopedia, London. pp. 1-365; 1-398.

Swainson, W. and J. Richardson. 1831. Fauna boreali-americana; or the zoology of the northern parts of British America. Part second, the birds. John Murray, London.

Taverner, P.A. 1916. List of specimens collected by Capt. Jos. Bernard on the Arctic Coast, N.W.T., Canada. Geological Survey of Canada, Summary Report for 1915:158-260.

______. 1919. Birds of eastern Canada. Geological Survey of Canada, Biological Series 1563, Memoir 104(3):1-297.

______. 1922. Birds of eastern Canada. Second Edition. Geological Survey of Canada, Biological Series 1564, Memoir 104(3):1-308.

Taverner, P.A. 1926. Birds of western Canada. Geological Survey of Canada, Museum Bulletin, Biological Series 10(41):1-380.

______. 1940. The nesting of Ross's Goose, *Chen rossi*. Canadian Field-Naturalist 54(9):127-130.

______. 1942. The distribution and migration of the Hudsonian Curlew. Wilson Bulletin 54(1):3-11.

______. 1953. Birds of Canada. Musson Book Company Ltd., Toronto. 446 pp.

Thomas, V.G. and S.D. MacDonald. 1987. The breeding distribution and current population status of the Ivory Gull in Canada. Arctic 40(3):211-218.

Todd, W.E.C. 1963. Birds of the Labrador Peninsula and adjacent areas. University of Toronto Press, Toronto. 819 pp.

Todd, W.E.C. and H. Friedmann. 1947. A study of the Gyrfalcon with particular reference to North America. Wilson Bulletin 59(3):139-150.

Townsend, C.W. and G.M. Allen. 1907. Birds of Labrador. Proceedings of the Boston Society of Natural History 23(7):277-428.

Tuck, L.M. and L. Lemieux. 1959. The avifauna of Bylot Island. Dansk Ornithlogisk Forenings Tidskrift, 53(3):137-154.

Turner, L.M. 1885. List of the birds of Labrador, including Ungava, East Main, Moose, and Gulf districts of the Hudson Bay Company, together with the island of Anticosti. Proceedings of the United States National Museum 8:233-254.

______. 1886. Contributions to the natural history of Alaska. Arctic Series, Publication of the Signal Service, United States Army 2:1-226.

Udvardy, M.D.F. 1969. Dynamic zoogeography with special reference to land animals. Van Nostrand Reinhold Co., New York. 445 pp.

Vieillot, L.J.P. 1807. Histoire naturelle des oiseaux de l'Amérique septentrionale, contenant un grand nombre d'espèces décrites ou figurées pour la première fois. (Tomes 1 et 2). Desray, Libraire, Paris.

Wallace, A.R. 1876. The geographical distribution of animals. (2 volumes). Reprinted in 1962. Hafner, New York. 503 pp.; 553 pp.

White, C.M. 1968. Diagnosis and relationships of the North American tundra-inhabiting Peregrine Falcons. Auk 85(2):179-191.

Wilson, A. 1808-1814. American ornithology or the natural history of birds of the United States. (9 volumes). Bradford and Inskeep, Philadelphia.

Witts, B. 1981. The Joint Services Expedition to Princess Marie Bay, Ellesmere Island, 1980. Part 1 - Initial report. Sea Swallow 30:15-21.

Wynne-Edwards, V.C. 1952. Zoology of the Baird Expedition (1950). The birds of central and south-east Baffin Island. Auk 69(4):353-391.

Yeatman, L.J. 1971. Histoire des oiseaux d'Europe. Bordas, Paris-Montreal. 363 pp.

Illustrated by Brenda Carter

MIGRATION, BODY CONDITION AND BEHAVIOUR OF SHOREBIRDS DURING SPRING MIGRATION AT ALERT, ELLESMERE ISLAND, N.W.T.

R.I.G. Morrison[1] and N.C. Davidson[2]

Abstract: Banding studies were carried out at Alert, N.W.T., during the period of arrival of shorebirds on their High Arctic breeding grounds in late May and early June in 1986 and 1987. Band recoveries and morphometric analysis have confirmed and extended earlier work showing that Ellesmere Island populations of Red Knots (Calidris canutus) and Ruddy Turnstones (Arenaria interpres) migrate to wintering areas on the northern European seaboard. Ellesmere Island knots are indistinguishable morphometrically from European wintering populations and from knots caught on migration in Iceland and northern Norway, the two major routes used by the birds to reach Nearctic breeding grounds.

Weights of banded birds and preliminary data from biochemical analysis of specimens obtained during the arrival period indicate that knots reach Alert with substantial reserves of both muscle protein and fat, though the amounts retained after migration may vary between years. In 1986 and 1987, weights of knots declined after arrival, reflecting a loss of both protein and fat. Time/activity budgets in 1987 showed that early migrants spent much time resting, and that little feeding occurred during severe weather and high winds in early June. Feeding and display activities both increased as snow-melt proceeded and habitat became available. Early season food was scarce, consisting mostly of plant material; the garbage dump was also used for foraging - particularly in 1986. Body reserves thus appear important for early season survival in High Arctic shorebirds. The contribution of such reserves to the physiological requirements of breeding requires investigation.

Résumé: Des études par bagage ont été effectuées à Alert, T.N.-O., pendant la période d'arrivée d'oiseaux de rivage sur leur lieu de nidification dans le Haut-Arctique à la fin de mai et au début de juin en 1986 et 1987. La récupération des bagues et l'analyse morphométrique ont confirmé et prolongé les premiers travaux qui montraient que les populations de bécasseaux à poitrine rousse (Calidris canutus) et de tourne-pierres (Arenaria interpres) de l'Île Ellesmere migrent dans des gîtes d'hivernage sur le littoral de l'Europe du nord. On ne peut distinguer morphométriquement les bécasseaux à poitrine rousse de l'Île Ellesmere des populations hivernant en Europe, ni des bécasseaux à poitrine rousse capturés lors de la migration en Islande, et dans le nord de la Norvège, sur les deux principales voies empruntées par les oiseaux en directions des lieux de nidification du Néarctique.

Le poids des oiseaux bagués et les données préliminaires provenant de l'analyse biochimique d'individus recueillis pendant la période d'arrivée indiquent que les bécasseaux à poitrine rousse atteignent Alert avec de bonnes réserves de protéines musculaires et de graisse, bien que les quantités restant après les migrations puissent varier d'une année à l'autre. En 1986 et 1987, le poids des bécasseaux à poitrine rousse a baissé après l'arrivée, ce qui reflète une perte de protéines et de graisse. Les bilans temps/activité de 1987 ont démontré que les premiers migrateurs passaient beaucoup de temps à se reposer et qu'ils se nourrissaient peu lors des périodes de mauvais temps et de grands vents du début de juin. L'alimentation et les parades augmentaient toutes deux à mesure que la neige fondait et que des habitats étaient disponibles. En début de saison, la nourriture était rare et se composait principalement de plantes. Les oiseaux se nourrissaient aussi à la décharge, en 1986 surtout. Les réserves de l'organisme semblent donc importantes pour la survie des oiseaux de rivage du Haut-Arctique en début de saison. Le rôle de ces réserves dans les besoins physiologiques de la reproduction demande une étude plus approfondie.

INTRODUCTION

Red Knots (*Calidris canutus*) and Ruddy Turnstones (*Arenaria interpres*) breeding on Ellesmere Island (Figures 1A,B), N.W.T. and in northwest Greenland migrate to wintering areas on the European seaboard (Salomonsen 1950-1951; Godfrey 1953; Morrison 1975, 1984). Until recently, most birds were thought to migrate via staging grounds in Iceland, where they spend two to three weeks putting on fat to fuel the last stage of the flight

---

[1] Canadian Wildlife Service, 1725 Woodward Drive, Ottawa, Ontario K1A 0H3
[2] Nature Conservancy Council, Northminster House, Peterborough PE1 1UA, U.K.

FIGURE 1A: Red Knot (Calidris canutus).

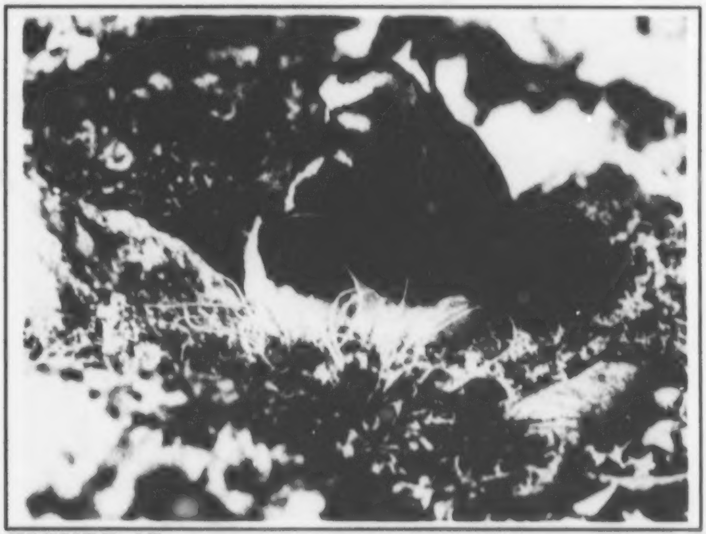


FIGURE 1B: Ruddy Turnstone (Arenaria interpres). Note camouflage of plumage.

across Greenland (Morrison 1977). Radar studies and band recoveries have suggested that after leaving Iceland, the birds reach their breeding grounds in northwestern Greenland and northeastern Canada by flying across the southern part of the ice cap and up the west coast of Greenland (Alerstam *et al.* 1986). Research in Norway, however, has now shown that a significant part of the population (estimated as 25-35%) may reach Nearctic breeding grounds via fiords in northern Norway: migrants passing through such areas in spring were previously thought to have been en route to breeding grounds in Siberia (Davidson *et al.* 1986; Uttley *et al.* 1987; Wood *et al.* 1988).

Staging grounds assume critical importance in the life-cycles of shorebirds, since the birds must accumulate adequate reserves of fat and protein to enable them to complete the next stage of their journey, which often involves a long-distance, non-stop flight over an 'ecological barrier', where they are unable to rest or feed. For shorebirds breeding in the High Arctic, late spring stopover areas assume particular importance, since the level of reserves the birds are able to accumulate will not only determine their ability to complete the journey successfully, but will influence the physiological condition of the birds on their arrival on the breeding grounds at a time when weather conditions are often difficult and food scarce. Reserves remaining after migration may be important for early season survival and/or may affect the subsequent capability of the birds to breed successfully. For instance, severe weather in June 1974 on Ellesmere Island led to widespread mortality from starvation among shorebirds (Morrison 1975). It is now widely accepted that arctic-breeding ducks and geese carry reserves of fat and protein to their breeding grounds, and that the size of these reserves affects the ability of the birds to breed successfully. Little is known about whether this phenomenon may occur in shorebirds, and these studies of the physiological condition of shorebirds immediately after arrival at Alert form part of a research program investigating the accumulation and use of fat and protein reserves during spring migration by arctic-breeding shorebirds. Accumulation of fat and protein reserves of knots at their late spring staging area in northern Norway is reported in Davidson and Evans (1986, in press). Based on studies of flight performance calculations, Davidson and Evans (in press) predicted that knots would arrive on their breeding grounds with substantial protein reserves remaining.

Our work at Alert, N.W.T., was undertaken as part of an internationally coordinated investigation to clarify the spring migration routes of Red Knots (Piersma 1984) and Ruddy Turnstones breeding in the northern Canadian Arctic on Ellesmere Island, and to investigate the physiological condition of the birds and their behaviour during the immediate post-migration period.

METHODS

Birds were captured at the garbage dump near Alert (82°30'N 62°20'W) for banding and for studies of weights and measurements, using mist-nets (1974-1976) and cannon-nets (1986-1987) (Figure 2). Wing lengths were measured to the nearest mm (maximum length of stretched and flattened wing) using a metal ruler, bill lengths to the nearest 0.1 mm using dial-calipers and weights to the nearest 1 g using a spring balance. Weather records were from the nearby weather station. In 1986 and 1987, tissue samples were collected for biochemical analysis (carried out using techniques described by Piersma *et al.* (1984)). In 1987, observations were made of the behaviour and activity of shorebird flocks in the vicinity of Alert at regular intervals on most days between 27 May and 9 June, whenever a bird

FIGURE 2: Guy Morrison bird banding at the garbage dump near Alert, Ellesmere Island in June 1986.

or birds were in view and undisturbed by humans. The activity of each bird was allocated to one of five categories: (1) roosting, when the bird had eyes closed and bill tucked into scapulars; (2) resting, with eyes open and bill pointing forwards; (3) feeding; (4) flying; and (5) displaying, including both aerial and ground courtship displays, and aggressive and territorial displays.

RESULTS

Migration

Arrival

Arrival dates of knots and turnstones on High Arctic breeding grounds in Canada and northwest Greenland are generally in the last few days of May or first days of June (e.g. Salomonsen 1950-1951, 1967; Parmelee and MacDonald 1960). At Alert, recorded arrival dates of knots included 29 May 1975 and 30 May 1987 and of turnstones 26 May 1976; both species were present by 31 May 1986 and turnstones by 27 May 1987. Numbers build up in the week following the first sightings and quite large flocks may occur. At Alert, knot counts reached 56 and 118 on 6 and 9 June 1974, respectively, 34 on 1 June 1975, 89 on 2 June 1976, 43 on 3 June 1986 and approximately 50 on 4-5 June 1987. Counts of turnstones have included 150 on 9 June 1976, 73 on 4 June 1986 and approximately 30 in the first few days of June 1987.

Banding

Banding in 1974-1976 resulted in the capture of 28 knots and 61 turnstones, and in the years 1986-1987 of 41 knots and 76 turnstones. A summary of international and local band recoveries and sightings is shown in Figure 3.

International Movements

Recoveries and controls of banded birds have significantly extended evidence establishing that knots and turnstones from northern Ellesmere Island migrate to European wintering grounds.

Records of banded knots at Alert have included a bird from England in 1974, a bird from Scotland recorded in both 1986 and 1987, and a bird carrying bands from Norway and England first captured at Alert in 1974 and seen again in 1976 (Figure 3). The double-banded bird was originally captured as a juvenile in 1971 in southwestern Norway during its first autumn migration and was caught again after having spent its first (subadult) summer on the east coast of Britain in July 1972, before being captured at Alert in 1974 (Morrison 1975). One bird banded at Alert in 1974 was controlled in England. Other records between Ellesmere Island and European wintering grounds were obtained during work on the east coast at Princess Marie Bay in 1980, and included the recovery of a knot banded in England and movements of three birds banded at Princess Marie Bay to England, Scotland and Denmark (unpublished results, Joint Services Expedition to Princess Marie Bay, 1980).

Records of banded turnstones in the mid-1970s included the first double-journey record between Ellesmere Island and Europe. This bird was banded on The Wash on the east coast of England in August 1972, was captured at Alert in early June 1975 and was caught again on The Wash in January 1976. A British banded bird was caught at Alert in 1976, and another banded during spring migration in Iceland in May 1972 was recovered on its breeding grounds at Lake Hazen in June 1975 (see Morrison 1976). A further indication that Iceland may be used as a stopover by turnstones from northeastern Canadian High Arctic breeding grounds comes from the recovery of two birds in northwest Greenland in the summer of 1974. They had been captured during migration at the same locality in Iceland in 1971 and 1972 (unpublished results). Records of movements to Ellesmere Island were significantly extended in the 1980s, with three birds from England and one from Scotland at Alert in 1986, and a second double-journey record of an English turnstone banded on the west coast of England in May 1985, captured at Alert in June 1987 and subsequently caught in the same wintering area in England in August 1987.

Return Data

Recaptures and resightings of marked knots and turnstones from year to year have established that the same birds used the Alert area year after year. Records of sightings of marked birds and of captures of banded birds are summarized in Figure 3, and include records between adjacent years (e.g. 1974 to 1975) as well as over two years (e.g. 1974 to

1976). For knots, four such sightings and one band recapture were made between years, in addition to the resighting of the double-banded (Norway/England) bird between 1974 and 1976 and the recapture of the Scottish-banded knot between 1986 and 1987 (see above, Figure 3A). For turnstones, a total of 16 resightings and three band recaptures were made between years (Figure 3B).

Local Movements

While counts indicate that some birds move through the Alert area en route to breeding-grounds in other areas, at least some birds that use the garbage dump for early-season foraging breed near Alert. In 1975, one pair of banded turnstones (both of which had been colour-marked at the garbage dump) was located by a nest with four eggs some 3 km east of Alert on the slopes overlooking Ravine Bay. Another marked bird was sighted about 11 km west of Alert near the mouth of Wood Creek.

MORPHOMETRICS

Bill-measurements of mixed-sex samples of adult knots and turnstones obtained at Alert and other locations, including breeding, migration and wintering-areas, are shown in Table 1. In both species, measurements show that birds using the Alert area may be identified with populations wintering in Europe, and are distinguishable from populations breeding and wintering in other areas.

Mean bill-lengths of knots from the breeding-grounds at Alert and from Greenland, from migration-areas in Iceland and in Norway, and from wintering-areas in the United Kingdom, all fell in the range 32.0-33.0 mm (Table 1A), and were generally not statistically significantly different from one another. This group (*Calidris canutus islandica*) was clearly smaller than knots of the nominate race (*C. c. canutus*) breeding in Russia and wintering in Africa, whose measurements on migration-areas in Europe averaged 35.1-33.7 mm (Piersma *et al.* 1987). The *islandica* group may also be distinguished from the North American race (*C. c. rufa*), where bill-measurements of birds on southward migration in James Bay averaged 35.2 mm. Differences in bill-measurements between *islandica* and the other two races were

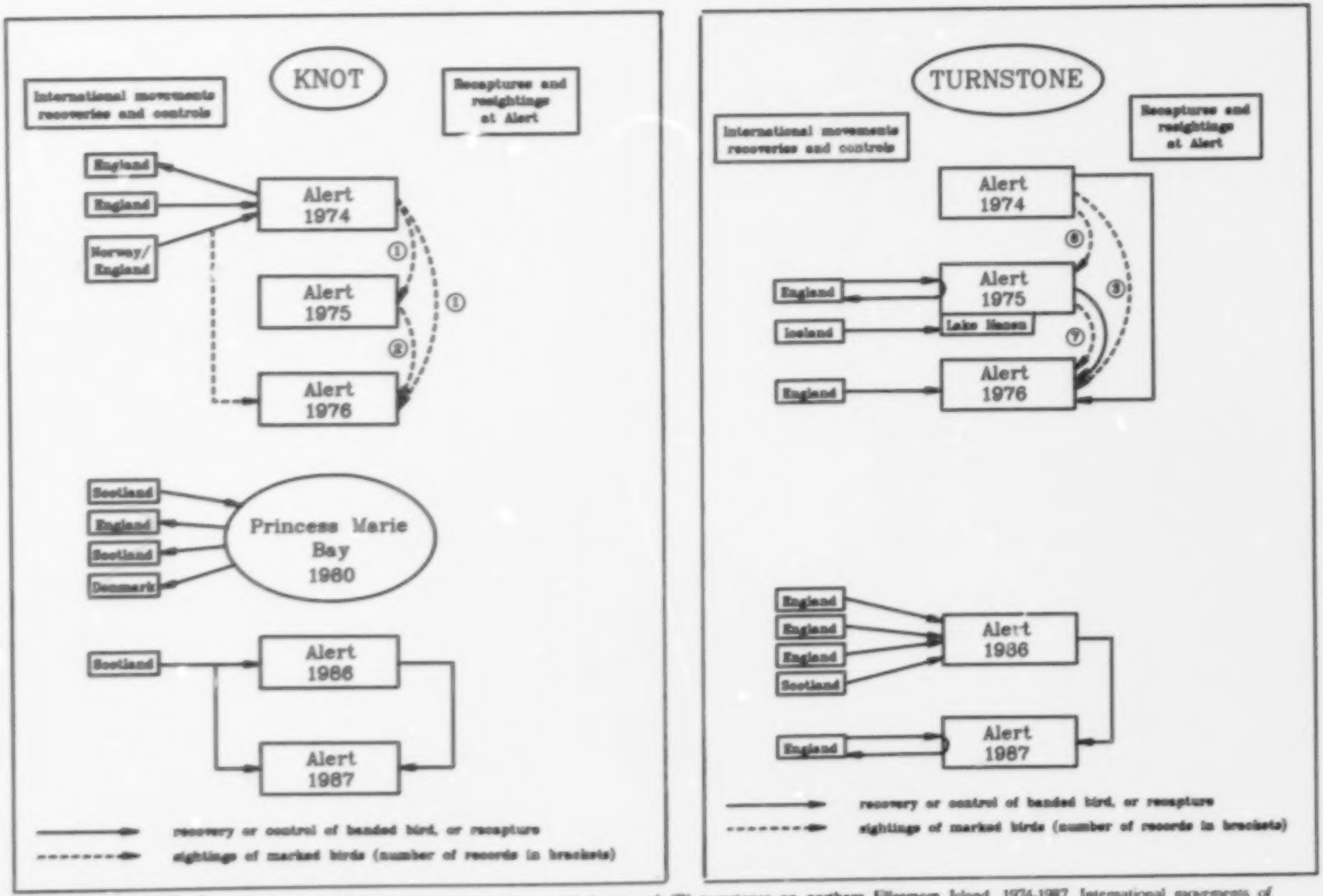

KNOT
International movements recoveries and controls
Recaptures and resightings at Alert
England
England
Norway/ England
Alert 1974
Alert 1975
Alert 1976
①
①
②
Scotland
England
Scotland
Denmark
Princess Marie Bay 1980
Scotland
Alert 1986
Alert 1987
recovery or control of banded bird, or recapture
sightings of marked birds (number of records in brackets)
TURNSTONE
International movements recoveries and controls
Recaptures and resightings at Alert
Alert 1974
Alert 1975
Alert 1976
⑥
③
⑦
England
Iceland
Lake Hazen
England
England
England
England
Scotland
Alert 1986
England
Alert 1987
recovery or control of banded bird, or recapture
sightings of marked birds (number of records in brackets)

FIGURE 3: A summary of banding records involving (A) knots and (B) turnstones on northern Ellesmere Island, 1974-1987. International movements of birds are shown on the left of the figures, with arrows indicating direction of movement from banding location to place of control (recapture) or recovery. (Between-year records of birds returning to Alert are shown on the right of the figures. Solid lines represent records involving a capture or recovery of a banded bird, whereas broken lines indicate sight records of marked birds (numbers indicate the number of sightings recorded).

TABLE 1: BILL MEASUREMENTS OF KNOTS AND TURNSTONES FROM ALERT AND OTHER LOCATIONS.

LOCATION	N	MEAN (MM)	S.D.	RANGE	REFERENCE[1]
(A) KNOT					
Calidris canutus islandica					
Alert (banding 1986)	40	33.0	2.07	28.7-38.1	
Alert (banding 1974)	23	32.0	1.47	30-35	(1)
Alert (specimens 1986-87)	32	32.5	2.13	28.3-35.7	
Iceland (W. Coast) (2 May 1972)	156	32.3	3.19	-----	(1)
Norway (Balsfjord) (May 1985)	96	33.0	1.81	28-38	(2)
Greenland	25	32.2	----	30.3-34.9	(3)
U.K. (Teesmouth)	59	32.5	1.72	29-38	(2)
Calidris canutus canutus					
Mauritania	280	35.1	1.78	-----	(4)
W-Central France	583	35.7	1.85	-----	(4)
Germany	291	35.1	1.86	-----	(4)
Calidris canutus rufa					
James Bay (July/August 1979)	43	35.2	1.76	32.5-39.0	(5)
(B) TURNSTONE					
Arenaria interpres interpres					
Alert (banding 1986)	53	22.3	1.24	20.6-24.9	
Alert (banding 1974)	35	21.9	1.17	20.0-24.2	(1)
Alert (specimens 1986-87)	28	22.1	0.91	20.1-24.1	
Iceland					
(3 May 1972)	33	22.9	0.98	-----	(1)
(23 May 1972)	44	21.5	1.06	-----	(1)
Netherlands	73	22.6	0.96	21-24	(3)
Siberia/Asia	24	21.9	0.79	21-23	(3)
Arenaria interpres morinella					
James Bay (July/August 1979)	49	23.0	1.15	20.6-25.5	(5)
South America	33	23.5	0.70	22-25	(3)

[1] Morrison (1975).

[2] Davidson and Evans (1986).

[3] Cramp and Simmons (1983).

[4] Piersma et al. (1987).

[5] R.I.G. Morrison (unpublished data).

statistically significant (t, d tests); differences within the *islandica* population, possibly resulting from a cline in size within the breeding-range (Morrison 1975), will be examined elsewhere.

Mean bill lengths of turnstones from Alert were again similar to birds of the nominate race (*Arenaria interpres interpres*) wintering in Europe: means from this group fell in the range 21.5-22.9 mm (Table 1B) - generally smaller than those of turnstones of the North American race *A. i. morinella* (23.0-23.5 mm). Statistical differences within the group will be explored more fully elsewhere.

FEEDING AND ACTIVITY PATTERNS

Weather

Maximum temperatures at Alert in late May/early June 1987 remained below freezing until 6 June, and had reached approximately 5°C when work finished on 9 June: minimum temperatures had still not reached 0°C by this date (Figure 4). Winds were generally northwesterly to northeasterly up to 3 June, with speed varying between 0 and 8 knots - apart from 27 May, when they rose to nearly 25 knots. Between 4-5 June, there was a period of relatively cold and bad weather, marked by strong, persistent northerly winds and a consistently high windchill factor (Figure 4). The weather became warmer and winds lighter and more variable from 6-9 June.

Behaviour

During much of the period 27 May to 9 June 1987, there was extensive snowcover around Alert, with snow melting rapidly only from 5 June onwards. In some previous years, including 1986, many birds of both species fed (with Long-tailed Jaegers *Stercorarius longicaudis*, Glaucous Gulls *Larus hyperboreus* and Ivory Gulls *Pagophila eburnea*) on the snow-free areas of the garbage dump. In contrast, very few knots and turnstones visited the garbage dump in 1987. Instead, the birds mostly frequented the snow-free patches on the slopes and around the sewage outfall pipe, between Alert, the airstrip and the frozen shoreline of Parr Inlet (an area approximately 3 km long and 0.5 km wide). Birds were mostly in small flocks throughout the period, but in the first week of June, turnstones were increasingly seen in pairs.

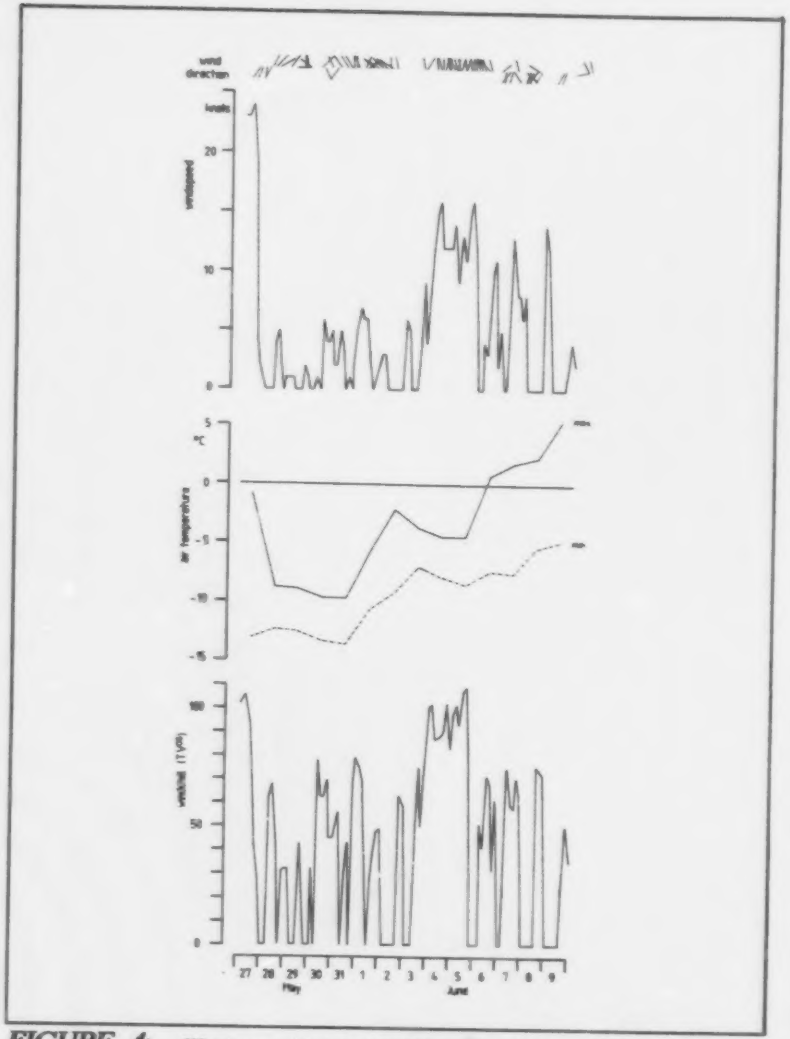


FIGURE 4: Weather at Alert in late May and early June 1987. Temperature, windspeed and wind direction are from hourly records at the Alert Meteorological Station. Windchill is calculated as $T.V^{2}$, where V is windspeed in knots, and T is the temperature deficit below 20°C (Davidson 1981B).

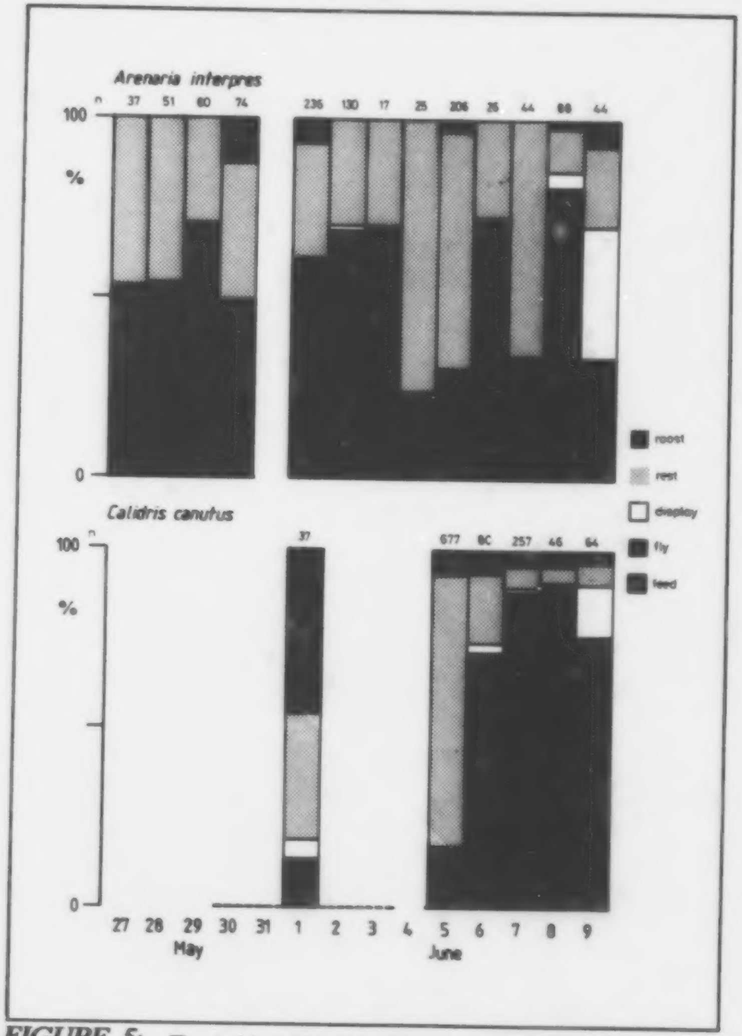


FIGURE 5: Time-activity budgets of knots and turnstones at Alert in late May and early June 1987. Data are shown for each day of observations, except for knots between 30 May and 3 June. Data for this period are lumped because few birds were present and few observations made. The number above each column gives the number of bird-observations on that day.

Both knots and turnstones spent much of their time resting or roosting immediately after their arrival at Alert (Figure 5). Between 28 May and 3 June, the time spent feeding by turnstones gradually increased from 35-40% to 70%. During the period of bad weather on 4-5 June 1987, both species spent most of their time resting, crouched and sheltering from the wind on the lee slopes of hills and hummocks. At this time, turnstones spent only 25% of their time feeding, and knots less than 15%. Before the bad weather, we did not see the few knots that were present in the area feeding. With improved weather from 6 June onwards, both species spent much more of their time feeding: knots 67-90% and turnstones 25-73%. Courtship activities became prominent in both species for the first time on 9 June. Although most observations were made between 0700 and 2300 local time, birds were seen feeding on occasion at all times of the day and "night". Arrival timings and behaviour suggests that, in 1987, turnstones were a few days more advanced in their activities than knots, which arrived at Alert mostly during and after the bad weather of 4-5 June. By 6 May, many of the turnstones appeared to be taking up breeding territories, and some birds were seen to fly from feeding areas around Alert more than 2 km across Parr Inlet, presumably to breeding sites on other slopes, such as those discovered in 1975 (see above).

Examination of gizzard contents revealed that birds were feeding on small seeds of various plants (unpublished observations). Feeding on seeds in the arrival period before insects emerge has been widely reported in arctic-breeding shorebirds, including knots and turnstones elsewhere on Ellesmere Island (Parmelee and Macdonald 1960; Nettleship 1973, 1974). The seed-bearing plants were scattered sparsely over the ground surface. During the two days of bad weather on 4-5 June, fine drifted snow covered most of the plants, which grew mostly in shallow depressions. When foraging, knots appeared to feed in a rather desultory manner for much of the time, in contrast to the rapid and active searching when feeding on mudflats just before departure in late May from their spring staging areas in northern Norway (Davidson and Evans 1986). Birds on the garbage dump took a wide variety of cooked and raw kitchen waste.

Many authors have reported that shorebirds spend much of their time soon after arrival at High Arctic breeding grounds loafing on snow-free patches of ground (e.g. Parmelee and MacDonald 1960), and have attributed this to birds waiting for the snow to melt sufficiently to expose feeding and nesting areas (Meltofte 1985). The considerable periods of the day spent not feeding by shorebirds at Alert during the two weeks after their arrival could either be because the birds did not need to feed for longer to satisfy their energy and nutrient demands, or because feeding was not profitable in the conditions that they faced. Both knots and turnstones became progressively more inactive as the windchill factor increased (Figure 6). High windchills mean high energy expenditure for thermoregulation. Hence shorebirds appear to be conserving energy by becoming inactive and seeking shelter when weather is poor. In turnstones, the trend of increased inactivity appears to begin when windchills are still quite low, so feeding on seeds may be worthwhile in the period soon after arrival only when the weather is fair and thermoregulatory demands are low. Birds were particularly inactive during periods of very high windchill during the bad weather of 4-5 June. Then, not only were energy demands high, but food was also barely available because drifted snow had covered the seed heads of most food plants.

BODY CONDITION

Detailed laboratory analysis of the physiological condition, including fat and protein content and muscle ultrastructure, of both knots and turnstones collected in 1986 and 1987 is in progress. Here we report preliminary results from this work.

Total Mass and Fat Load

Much of the variation in the total mass of shorebirds during the course of the year is a consequence of changes in fat load, although the lean mass can also vary substantially at times. Any variation in lean mass would modify the apparent fat load, but total body mass in spring usually reflects trends in fat loads (e.g. Davidson *et al.* 1986). Total body masses of knots and turnstones during the two weeks after their arrival at Alert are shown in Figure 7. For 1986 and 1987, mass was measured over periods of a week or more. Mass measurements collected over shorter periods in 1974 and 1975 are also shown in Figure 5 for further year-to-year comparisons. Total mass varies partly with the body size of the birds; however, the same trends as in Figure 7 remained after the effects of body size were allowed for by dividing total mass by wing-length. Data in Figure 7 come both from birds weighed during banding and from those collected for analysis of body condition.

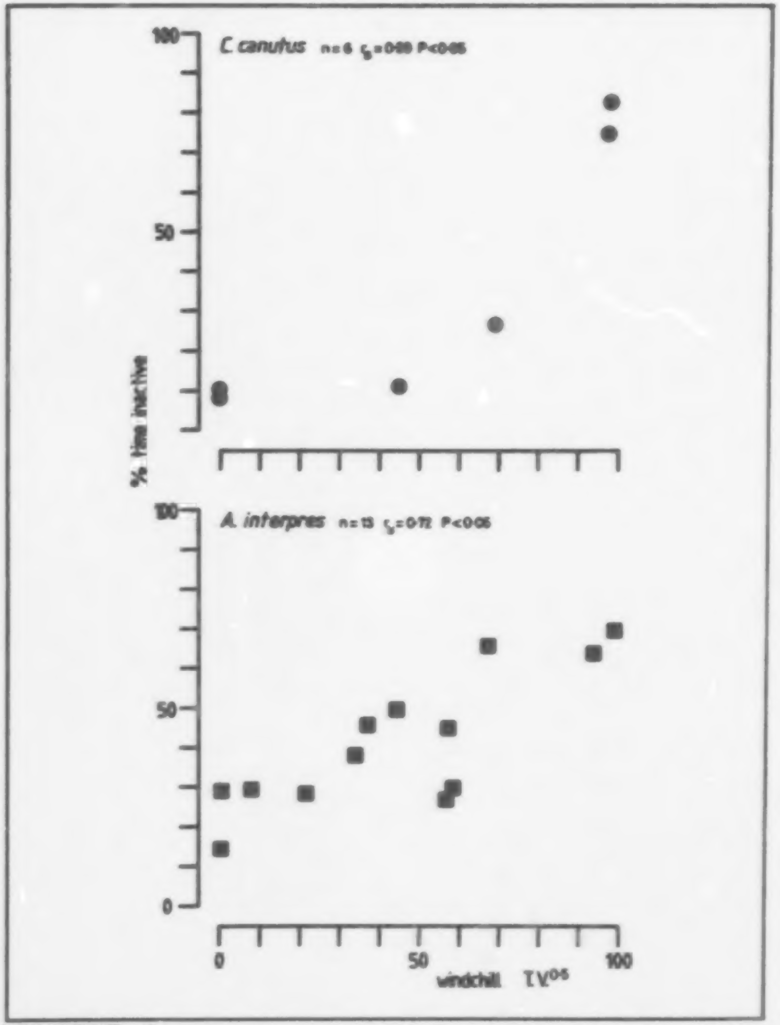


FIGURE 6: The relationship between the percentage of time spent inactive (roosting and resting) and windchill. Each data point is the mean activity during a bout of observations of up to three hours, with a minimum of 10 bird-observations, and the mean windchill during that period.

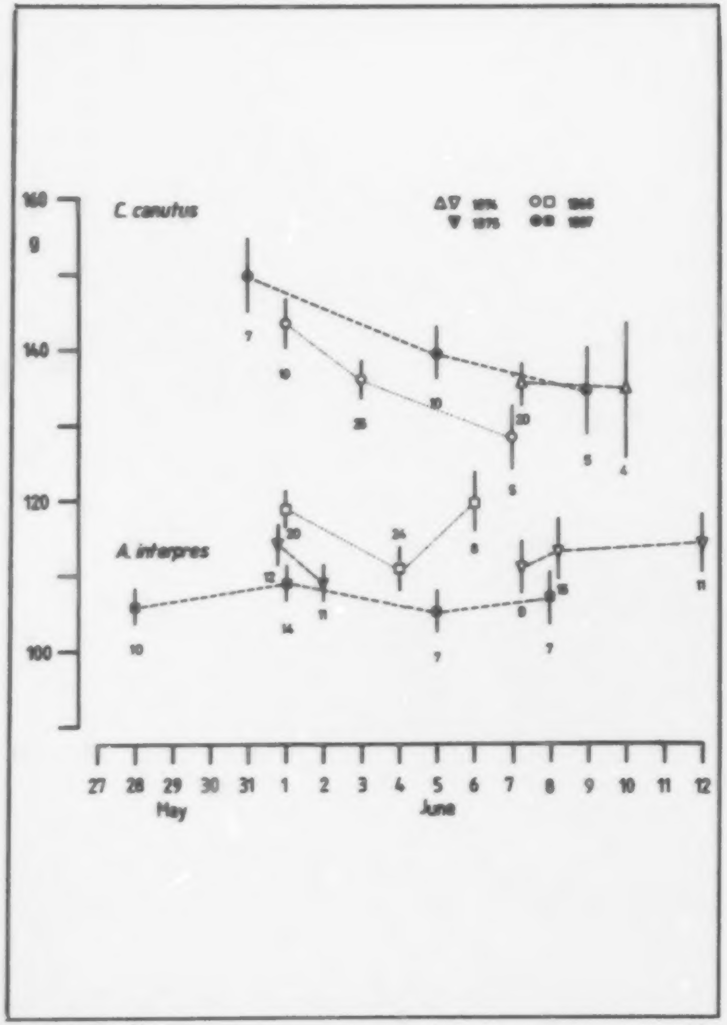


FIGURE 7: Total body mass of knots and turnstones at Alert in late May and early June in 1974, 1975, 1986 and 1987. Each point shows the mean ± 1 standard error; numbers give sample sizes. Each sample is from a period of 1-3 days, and is plotted on the median date of sampling.

Birds weighed in 1987 were almost all feeding on snow-patches on the slopes around Alert, whereas birds weighed in other years had also fed on the garbage dump.

Body mass of knots decreased significantly between late May and mid-June in both 1986 ($r = -0.33$, $n = 40$, $p < 0.05$) and 1987 ($r = -0.57$, $n = 22$, $p < 0.01$). When mass was corrected for differences in body size (by dividing mass by wing length) the trend remained, and the correlations improved: 1986, $r = -0.40$, $n = 40$, $p < 0.02$; 1987, $r = -0.68$, $n = 22$, $p < 0.001$. Mean mass decreased by 15 g in nine days in 1987, and by 15 g in six days in 1986. Mean mass in 1986 was consistently 5-10 g less than for the same date in 1987. Between 7-12 June 1974 (i.e. approximately a week after the date of first arrivals), mass was similar to that in 1987. In 1987, the decrease continued both immediately after the first arrivals, and during the period of bad weather when the birds fed very little (Figure 5).

The mean mass of the first sample of knots in 1987 was 150 g, and was obtained within a few hours of the first observed arrival of the species at Alert. In comparison, knots of the same breeding population arrive on staging areas in Iceland in early May averaging approximately 135 g, with mean masses rising to some 200 g before departure near the end of the month (Morrison 1977, 1984). In northern Norway, knots arriving at their final spring staging site at Balsfjord weighed an average of 151 g, with a fat load of 11% of total body mass (Davidson and Evans 1986). However, the fat loads of knots arriving at Alert in late May and early June may be substantially higher than this, since preliminary results of laboratory analysis of samples collected in early June 1986 suggest that fat loads averaged 16% with an average body mass of only 143 g. This also implies that lean masses were lower in birds arriving at Alert than at Balsfjord. Whatever the precise amounts of fat carried on arrival, it is clear that knots arrive at their breeding grounds after a migratory flight of about 3,000 km (Davidson and Evans 1986) with substantial amounts of fat remaining. This confirms Davidson and Evans's (in press) prediction of arrival condition, made from the storage and use of reserves during earlier parts of their spring migration. Knots leave Balsfjord in late May with fat loads averaging 30% of total body mass (Davidson and Evans, in press), so appear to use only about half this fat load by the time they arrive in Ellesmere Island after one of the longest non-stop migratory flights known. Fat loads of knots on arrival at Alert are comparable with those in midwinter in northeastern England, and would be sufficient for survival for several days of severe weather without food (Davidson 1981A,B).

The steady decrease in mean total mass of knots during early June could arise in two ways: (1) individual birds lose mass by using up their fat reserves after their arrival at Alert; or (2) later arrivals reach Alert with lower masses than earlier birds, perhaps because fat reserves useful for survival in severe weather would be needed for a shorter period than faced by the early-arriving birds.

It was not possible to mark knots individually in 1986 or 1987, so it is not clear if the first arrivals remained at Alert during the following two weeks. Nor can the two alternative reasons for mass decline yet be distinguished. Only a few knots have been caught and recaptured at Alert. One bird caught on 8 June 1974 had gained 13 g when it was recaptured two days later, at a time when the mean total mass changed little. Two knots were weighed in both 1986 and 1987. One weighed 141 g on a 4 June 1985 and 140 g on 6 June 1987. The other weighed 127 g on 3 June 1986, but was 11 g heavier on the same date in 1987. This suggests that the difference in the mean mass between 1986 and 1987 is a consequence of poorer arrival condition of the same individual knots in 1986 compared to 1987.

The pattern of mass change in turnstones differs from that in knots. Mean total mass in 1987 changed little between late May and early June (Figure 7). Mass was lowest during the bad weather of 4-5 June, but at this time averaged only 4 g less than in the previous three days. Nineteen turnstones were individually colour-marked in 1987. Many of these remained around Alert throughout early June, and probably comprised the local breeding population. Two turnstones were recaptured during 1987. One had gained 11 g between 3 and 8 June, even though it had a damaged foot. The other weighed 114 g on 1 June, but had lost 9 g when reweighed on 5 June, during the bad weather. These results imply that in 1987 turnstones were able to maintain their body condition after arrival at Alert, with at most only slight use of reserves during the bad weather.

In contrast to knots, in which mass was lower in 1986 than 1987, the mass of turnstones was consistently higher in 1986 than 1987 (Figure 7). Total mass also fluctuated with time; the decline in mean mass of almost 8 g between 1-2 June and 3-4 June is significant (Student's $t = 2.30$, $n = 42$, $p < 0.01$). In between-year comparisons, mean masses were significantly higher in 1986 in the samples weighed on 1-3 June, and 5-7 June

(Student's t test, both $p < 0.01$). Only one turnstone was weighed in both years. This bird was of similar mass in both years: 115 g on 1 June 1986 and 114 g on 28 May 1987. Data from 1974 and 1975 suggest that condition in these years was intermediate between 1986 and 1987 (Figure 7). Masses in mid-June 1974 suggest that there may be a gradual increase in most years after about 5 June. Two birds recaptured in early June 1974 suggest that the decrease in mass between late May and early June of that year may reflect some use of reserves by individuals: one bird lost 6 g between 1 and 2 June, the other lost 1 g between 31 May and 2 June.

Preliminary results from 1986 suggest that turnstones, like knots, carry substantial fat reserves soon after arrival on the breeding grounds. Birds in early June 1986 averaged 19% fat. If lean masses were similar in 1986 and 1987, then even the much lower total mass in late May 1987 (mean 106 g) would still represent a fat load of approximately 10%.

Pectoral Muscle Size

Pectoral muscle size is a good measure of the protein reserves of shorebirds (Davidson *et al.* 1986). Davidson and Evans (in press) showed that knots accumulate protein reserves in their pectoral muscles on spring staging areas, and predicted that much of this reserve would be retained during the flight to the breeding grounds. Full laboratory analysis of pectoral muscle size is in progress. This will allow calculation of a Standard Muscle Index (SMI) (the lean dry mass of the pectoral muscles corrected for body size by dividing by a Standard Muscle Volume (SMV) based on skeletal measures) (Piersma *et al.* 1984; Davidson and Evans, in press). An initial indication of changes in pectoral muscle size is given by the fresh mass of the muscle, corrected by "f", the diagonal measurement from the posterior point of the sternum to the distal point of the coracoid bone. This is shown for pectoralis major (the main flight muscle) size in Figure 8. In knots, muscle size was similar in late May and early June in 1986 and 1987. Immediately before their departure from Balsfjord, this measure of muscle size in knots averaged 0.254 (unpublished data). Arrival condition of the first knots in 1987 averaged 0.230, so that pectoral muscle size appeared to have decreased by only about 9% during a flight from Norway to Ellesmere Island. This decrease is a maximum, since part is likely to be a decrease in the fat content of the muscles. The decrease is very close to 10% predicted by Davidson and Evans (in press).

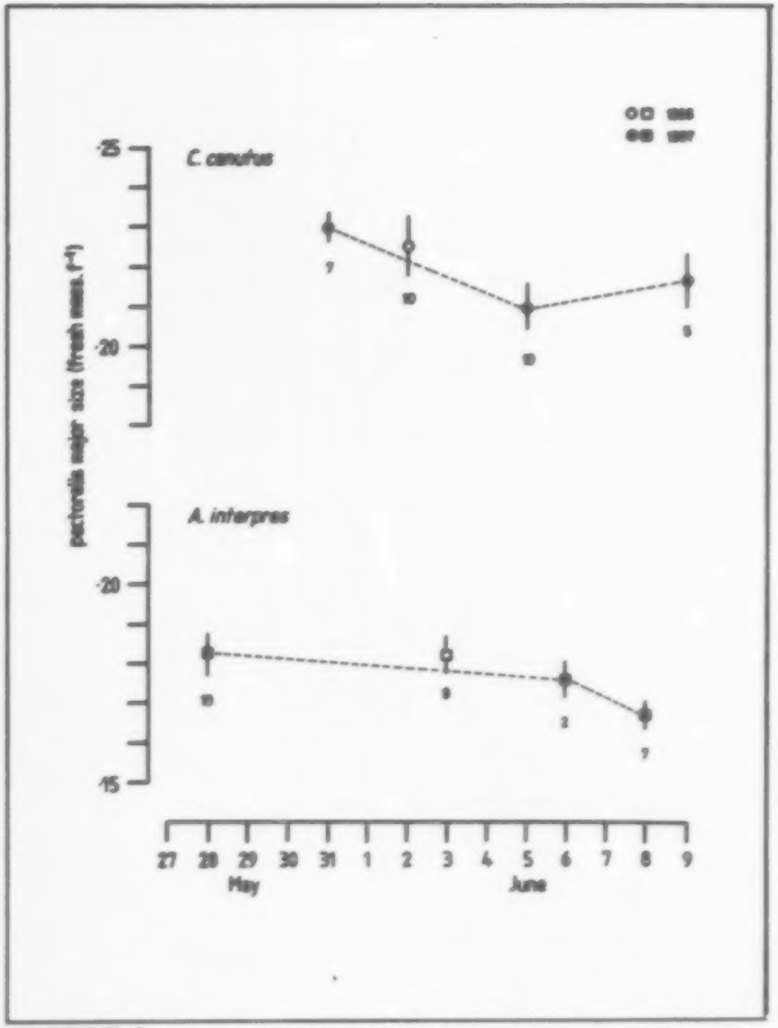


FIGURE 8: Pectoralis major muscle size of knots and turnstones in late May and early June 1986 and 1987. Pectoralis-major size is shown as the fresh mass of the muscle (g), corrected for body size by dividing by f (mm), the measurement from the posterior point of the keel to the distal point of the coracoid bone. Each point shows the mean ± 1 standard error; numbers give sample sizes. Each sample is from a period of 1-3 days, and is plotted on the median date of sampling.

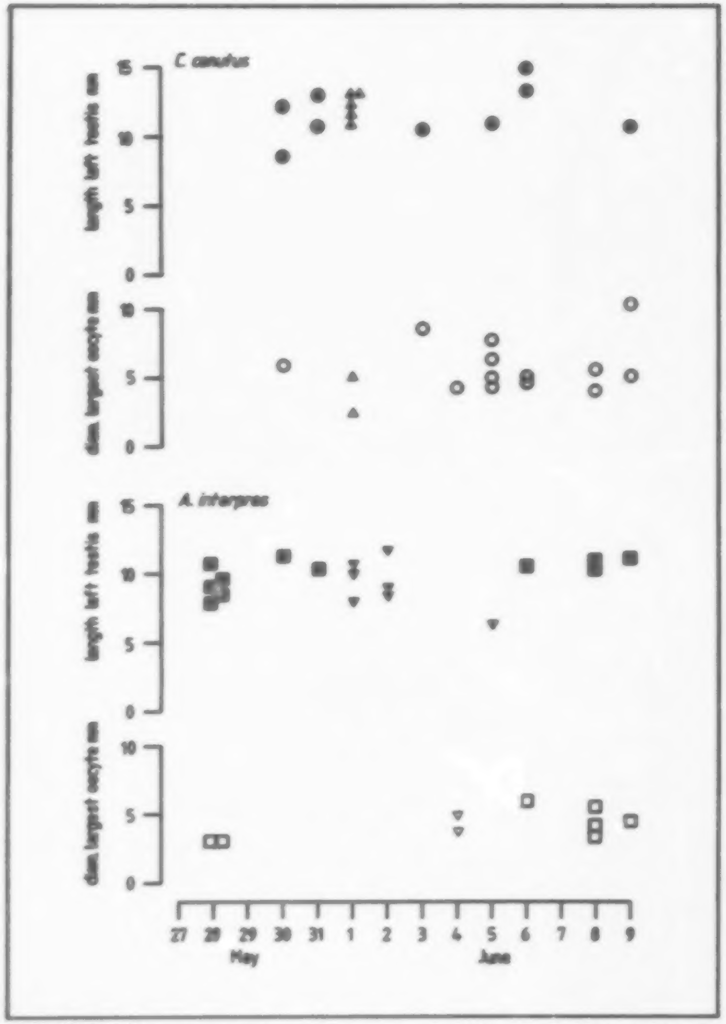


FIGURE 9: Reproductive condition of male (left testis) and female (largest oocyte) of knots and turnstones in late May and early June 1986 (triangles) and 1987 (circles knots, squares turnstones).

This provides first confirmation that knots arrive on their breeding grounds with substantial protein reserves.

The muscle size of knots decreased significantly during early June 1987 (Student's $t = 3.02$, $n = 17$, $p < 0.05$), but increased slightly after the bad weather on 4-5 June. The decrease in total mass could result either from use of protein reserves by birds during the cold spell when they fed little, or from the later arrival of birds with smaller pectoral muscles.

Pectoral muscle size in turnstones was the same in late May 1987 as in early June 1986 (Figure 8). Between late May and 8-9 June 1987, muscle size decreased by 8%, although the difference was not significant. This measure of muscle size is probably not directly comparable between species, as the form of the sternum may differ interspecifically. However, initial analyses of turnstone muscles from 1986 suggest that the Standard Muscle Index of the pectoralis major is about 0.28, which is similar to the muscle size in Britain in midwinter (Davidson 1981A). As pectoral muscles in midwinter are known to contain a substantial amount of protein reserve, so turnstones, like knots, must arrive on their arctic breeding grounds with substantial protein reserves.

REPRODUCTIVE CONDITION

The testes of males and the oocytes of females of both species appear not to be fully formed when the birds arrive at Alert, since the gonads increased in size between late May and early June (Figure 9). By mid-June, the testes of both species and the oocytes of turnstones had reached sizes similar to those of the respective peak sizes recorded by Nettleship (1973, 1974) on the Lake Hazen breeding grounds, about 80 km to the south in mid-June. In Nettleship's study, egg laying began at Lake Hazen on 10 June in turnstones and 15 June in knots. By analogy, the gonad size of knots and turnstones at Alert suggests that egg laying would begin within a few days after our work finished on 9 June.

DISCUSSION

Davidson and Evans (in press) predicted that shorebirds arrive on their arctic breeding-grounds with substantial reserves of fat and protein. They suggested that these reserves were needed for birds to survive through periods of severe weather soon after their arrival on the breeding grounds, when little food is available. Even when they carry such reserves, knots and turnstones are known to suffer occasional heavy mortality during prolonged severe weather, as reported for Ellesmere Island in the early 1970s (Morrison 1975). Davidson and Evans (in press) suggested that any reserves remaining at the start of the breeding attempt could then be used in breeding, perhaps by contributing a substantial proportion of the protein needed by females for egg formation. Reserves carried by males might allow more time for territorial and courtship activities by reducing feeding time.

Some previous evidence has suggested that shorebirds arrive on their arctic breeding grounds with fat reserves (Meltofte 1985). Our results from Alert provide the first confirmation that knots and turnstones carry substantial reserves of both fat and protein to arctic breeding grounds. Preliminary results indicate that part of these reserves are used to supply nutrient and energy demands in the two weeks after arrival, during even short spells of bad weather. This is not surprising, since we have shown that foraging was reduced as the windchill factor (and so the energetic costs of thermoregulation) increased. This is likely to arise because of the low availability of food shortly after the snow melts: in the two days of bad weather in early June 1987, snow covered most of what little food was available, and both knots and turnstones almost ceased feeding. Nevertheless, the relatively steady average total masses of turnstones through late May/early June 1987 suggest that these birds were mostly able to balance their energy requirements from the available food. This was achieved largely by feeding on natural vegetation on snow-free patches of tundra, rather than the artificial food source at the garbage dump.

The differences in the total masses of both knots and turnstones between 1986 and 1987 suggest that birds may arrive at Alert with different amounts of fat, and possibly protein, reserves in different years. This could arise through year-to-year differences in body condition when the birds depart from their late spring staging areas. It could also arise if birds faced varying weather conditions (e.g. head winds, during their flight to the breeding grounds), or from a combination of both factors.

We have found no evidence that knots or turnstones are able to increase their reserves appreciably after they arrive on the breeding grounds. However total masses from several years show that shorebirds retain substantial reserves of fat shortly before egg-laying begins. Similarly, pectoral-muscle size in 1987 indicates that both knots and turnstones usually enter the egg laying period with a protein reserve in their muscles. Shorebirds thus appear to prepare for an arctic breeding attempt in a similar manner to arctic-breeding geese, which carry fat and protein reserves to the breeding grounds for use in the breeding attempt (Ankney 1984; Mainguy and Thomas 1985).

Earlier studies have shown that knots and other shorebirds begin to accumulate fat and protein reserves on their late winter feeding grounds, before accumulating further reserves on spring staging areas. Our results suggest that arrival on the breeding grounds with sufficient fat and protein reserves is vital for the survival and breeding of these populations. Hence, the continued presence of wintering and of staging sites with an abundant food supply, which will enable the birds to accumulate energy reserves as well as meet their daily requirements, is also vital for the continued survival of these species. Many of the estuaries used by shorebirds in western Europe, the New World, and elsewhere, are threatened by land-claims and a wide variety of other human influences (e.g. Morrison 1984; Senner and Howe 1984; Smit *et al.* 1987). Even in the remote fiords used by knots in northern Norway in spring, intertidal feeding grounds are being lost through road improvements on the upper parts of the shore, so reducing the period of the tidal cycle available for the birds to feed.

Most studies of arctic birds have focused on their migrations or on the breeding attempt itself. Our recent studies of shorebirds at Alert have produced information on a short but critical part of the annual cycle about which very little was previously known. However, many questions remain unanswered. For instance, we do not know yet precisely which late spring staging areas are used by the knots and turnstones that reach Alert. Knots may come from either of the two main areas used in late spring: northern Norway and western Iceland. Detailed information on the departure condition of knots exists only for Norway (Davidson and Evans 1986, in press). However, total mass measurements from Iceland in the early 1970s (Morrison 1977, 1984) suggest a similar departure condition from the two areas. The distances from Iceland and Norway to Ellesmere Island are similar, so we could expect arrival condition at Alert to be similar in birds arriving from the two staging areas. In any case, recent evidence suggests that individual knots use different staging areas in different years (Uttley *et al.* 1987). Much less is known about the spring migration of turnstones, but most are thought to pass through Iceland (Cramp and Simmons 1983), as indicated by the band recovery between Iceland and Ellesmere Island (Morrison 1976).

Further investigations are planned to clarify the relationship between activity and weather conditions, how this affects the use of fat and protein reserves in the pre-breeding period, and how any reserves retained during this period are then used in breeding.

ACKNOWLEDGEMENTS

This work was supported logistically and financially by the Canadian Wildlife Service as part of its Shorebird Project. We are most grateful for financial support through a grant from the North Atlantic Treaty Organization enabling international collaboration to take place. We thank John Uttley and Professor Peter Evans (University of Durham, England) for information on body condition of shorebirds in 1986.

We particularly thank the Canadian Armed Forces for permission to work at Alert, and for their thoroughly professional and enthusiastic support in all aspects of the project, with special thanks to the Commanding Officer and staff at Alert. We also acknowledge with thanks the assistance of Atmospheric Environment Service staff at the Alert Weather Station, and Polar Continental Shelf Project staff for their support of the work in the 1970s.

REFERENCES

Alerstam, T., C. Hjort, G. Hogstedt, P.E. Jonsson, J. Karlsson, and B. Larsson. 1986. Spring migration of birds across the Greenland Inlandice. Meddelelser om Grønland, Bioscience 21:1-38.

Ankney, C.D. 1984. Nutrient reserve dynamics of breeding and molting Brant. Auk 101:361-370.

Cramp, S. and K.E.L. Simmons. (Editors). 1983. The birds of the western Palearctic. Volume 3. Oxford University Press, Oxford. 913 pp.

Davidson, N.C. 1981A. Seasonal changes in the nutritional condition of shorebirds (Charadrii) during the non-breeding seasons. Ph.D. thesis, University of Durham, U.K.

______. 1981B. Survival of shorebirds (Charadrii) during severe weather: the role of nutritional reserves. In: Feeding and Survival Strategies in Estuarine Organisms. Edited by: N.V. Jones and W.J. Wolff. Plenum Press, New York and London. pp. 231-249.

Davidson, N.C. and P.R. Evans. (Editors). 1986. The ecology of migrant knots in north Norway during May 1985. Department of Zoology, University of Durham, U.K. Report SRG86/1.

______. (in press). Prebreeding accumulation of fat and muscle protein by Arctic-breeding shorebirds. Proceedings of the XIX International Ornithological Congress, Ottawa. Canada.

Davidson, N.C., P.R. Evans, and J.D. Uttley. 1986. Geographical variation of protein reserves in birds: the pectoral muscle mass of Dunlins *Calidris alpina* in winter. Journal of Zoology (London) 208:125-133.

Davidson, N.C., K.-B. Strann, N.J. Crockford, P.R. Evans, J. Richardson, L.J. Standen, D.J. Townshend, J.D. Uttley, J.R. Wilson, and A.G. Wood. 1986. The origins of Knots *Calidris canutus* in arctic Norway in spring. Ornis Scandinavica 17:175-179.

Davison, N.C., J.D. Uttley, and P.R. Evans. 1986. Geographic variation in the lean mass of Dunlins wintering in Britain. Ardea 74:191-198.

Godfrey, W.E. 1953. Notes on Ellesmere Island birds. Canadian Field-Naturalist 67:89-93.

Mainguy, S.D. and V.G. Thomas. 1985. Comparison of body reserve buildup and use in several groups of Canada Geese. Canadian Journal of Zoology 63:1765-1772.

Meltofte, H. 1985. Populations and breeding schedules of waders, Charadrii, in High Arctic Greenland. Meddelelser om Grøland, Bioscience 16:1-43.

Morrison, R.I.G. 1975. Migration and morphometrics of European Knot and Turnstone on Ellesmere Island, Canada. Bird-Banding 46:290-301.

_____. 1976. Further records, including the first double-journey recovery, of European-banded Ruddy Turnstones on Ellesmere Island, N.W.T. Bird-Banding 47:274.

_____. 1977. Migration of arctic waders wintering in Europe. Polar Record 18:475-486.

_____. 1984. Migration systems of some New World shorebirds. In: Shorebirds: Migration and Foraging Behavior. Edited by: J. Burger and B.L. Olla. Plenum Press, New York and London. Behavior of Marine Animals 6:125-202.

Nettleship, D.N. 1973. Breeding ecology of Turnstones *Arenaria interpres* at Hazen Camp, Ellesmere Island, N.W.T. Ibis 115:202-217.

______. 1974. The breeding of the Knot *Calidris canutus* at Hazen Camp, Ellesmere Island, N.W.T. Polarforschung 44:8-26.

Parmelee, D.F. and S.D. MacDonald. 1960. The birds of west-central Ellesmere Island and adjacent areas. National Museum of Canada, Bulletin 169:1-103.

Piersma, T. 1984. International wader migration studies along the East Atlantic Flyway during spring 1985. Wader Study Group, Bulletin 42:5-9.

Piersma, T., N.C. Davidson, and P.R. Evans. 1984. Estimation of the protein reserve of waders: the use and misuse of Standard Muscle Volume. Wader Study Group, Bulletin 42:19-22.

Piersma, T.O., D. Bredin, and P. Prokosch. 1987. Continuing mysteries of the spring migration of Siberian Knots: a progress note. Wader Study Group, Bulletin 49:9-10.

Salomonsen, F. 1950-1951. Grønlands Fugle/The Birds of Greenland. (3 volumes). Ejnar Munksgaard, København. 609 pp.

______. 1967. Fuglene pa Grønland. Rhodes, København. 341 pp.

Senner, S.E. and M.A. Howe. 1984. Conservation of Nearctic shorebirds. In: Shorebirds: Breeding Behavior and Populations. Edited by: J. Burger and B.L. Olla. Plenum Press, New York and London. Behavior of Marine Animals 5:379-421.

Smit, C., R.H.D. Lambeck, and W.J. Wolff. 1987. Threats to coastal wintering and staging areas of waders. Wader Study Group, Bulletin 49 (Supplement):105-113.

Uttley, J.D., C.J. Thomas, N.C. Davidson, K.B. Strann, and P.R. Evans. 1987. The spring migration of Nearctic Knots *Calidris canutus islandica*: a re-appraisal. Wader Study Group, Bulletin 49 (Supplement):80-84.

Wood, A.G., K-B. Strann, F.L. Symonds, and S. Nilsen. 1988. Knot research at Porsangerfjord. University of Durham, U.K. (Unpublished report).

Illustrated by Brenda Carter

WINTER STUDIES OF BIRDS AND MAMMALS IN THE CANADIAN ARCTIC ISLANDS

David R. Gray[1]

Abstract: Despite the recent increase in biological research in the High Arctic, our knowledge of the life history of arctic birds and mammals throughout the entire year is still rudimentary. In many cases, observations made by the personnel of early arctic exploring expeditions are still the basis of our knowledge of certain species in winter. This lack of recent information on the winter period means that much largely anecdotal information, still unconfirmed by modern studies, is being published in current general texts on the Arctic. The establishment of biological research stations at several High Arctic localities, and the logistical support of the Polar Continental Shelf Project facilitated overwintering studies of muskoxen and other projects. Further cooperation with weather-station personnel, Inuit hunters and others will augment future biological research. New studies of terrestrial and marine mammals and migrating birds at both ends of the winter period are only slowly moving us closer to an acceptable level of knowledge of the High Arctic fauna.

Résumé: Malgré la récente augmentation de la recherche biologique dans le Haut-Arctique, nos connaissances sur la vie des oiseaux et des mammifères arctiques durant l'année complète sont encore rudimentaires. Dans bien des cas, les observations faites par les membres des toutes premières expéditions dans l'Arctique constituent encore la base de nos connaissances sur certaines espèces en hiver. Ce manque d'information récente sur la période hivernale signifie que beaucoup d'informations, largement anecdotiques, toujours pas confirmées par des études modernes, sont actuellement publiées dans des textes généraux sur l'Arctique. L'établissement de stations de recherche biologique au sein de plusieurs localités du Haut-Arctique et le soutien logistique de l'Étude du plateau continental polaire ont facilité les études sur l'hivernage des boeufs musqués, ainsi que d'autres projets. Une coopération plus poussée avec le personnel de stations météorologiques, les chasseurs inuit et d'autres personnes aura pour effet d'améliorer les futures recherches biologiques. De nouvelles études sur la animaux marins et terrestres et sur les oiseaux migrateurs au début et à la fin de la période hivernale ne nous rapprochent que très lentement d'un niveau de connaissances acceptable sur la faune du Haut-Arctique.

INTRODUCTION

If the Canadian Arctic Islands are "Canada's Missing Dimension", then it could be said on another level that the winter season is the missing dimension of the Arctic Islands. Despite a recent increase in biological research in the islands, our knowledge of birds and mammals in winter is still rudimentary. For purposes of this paper, I define winter as the period from September to April; roughly the time when the mean temperature in the central Arctic Islands is below 0°C and the sun is below the horizon for at least part of the day.

In some cases, the observations recorded in explorers' journals from the 1800s are still the basis of information presented in schools, as well as scientific and popular books. A definite lack of new information on the Arctic winter, plus the time-lag of getting what little information there is to the public, means that the same old material continues to permeate the modern popular literature.

---

[1] Zoology Division, National Museum of Natural Sciences, Ottawa, Ontario K1P 6P4.

In magazines, children's books, and television films, we find two disturbing extremes. The first is the old, yet continuing notion of the Arctic as a land of year-round ice, snow, darkness, and howling winds. Summer is forgotten or dismissed for its brevity. The second is a newer misconception resulting from the increased accessibility of the Arctic to tourists and professional photographers - mainly in summer. So the public are overexposed to the other extreme, with misleading masses of flowering plants and breeding birds. One example is Hummel's (1984) book " Arctic Wildlife" containing 150 photographs, not one of which was taken in winter.

Apart from the general problem of satisfactorily communicating scientific results to the public, I am particularly concerned that little biological work has been done during the arctic winter in recent years. Many useful observations have been made, but some (not part of a specific study) are unlikely to be published, whereas others are parts of long-term studies awaiting completion.

OVERWINTERING STUDIES

Historical

Most early information on birds and mammals in winter comes from the journals of many expeditions in search of the North-West Passage or the North Pole. Because of the nature of such expeditions the information is usually not extensive (Figure 1). The records from those expeditions accompanied by an official naturalist are, of course, the most valuable. Fielden's (1877A,B) accounts are of particular interest. Of the many expeditions which overwintered in the Arctic Islands, perhaps one of the most biologically significant was that of William Parry, who spent the winter of 1819-1820 on Melville Island. The overwintering party observed muskoxen and caribou, recorded observations of Ravens in mid-winter, and ptarmigan in February (Fisher 1821). Observations made by Parry's group were used extensively by early writers on northern wildlife, and some are still useful.

The First International Polar Year (1882-1883) produced more information on High Arctic birds and mammals through the observations made during the American Expedition

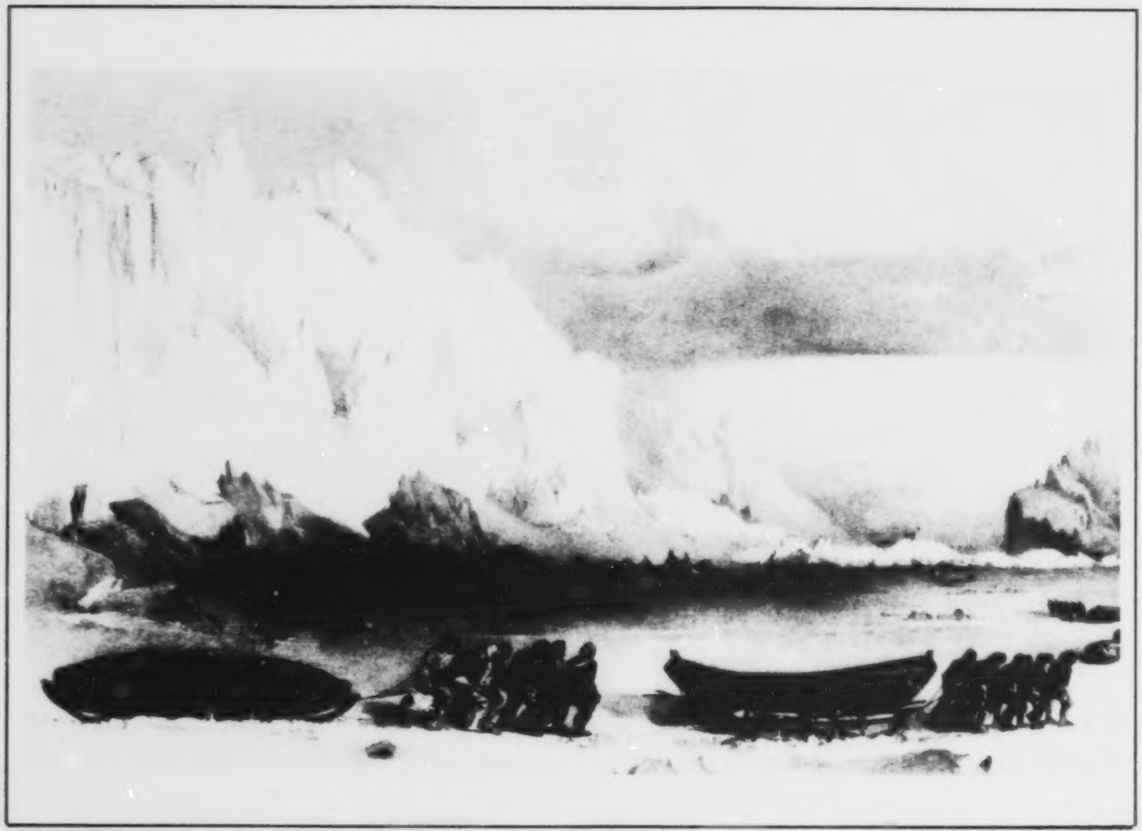


FIGURE 1: Sledges of the British naval Franklin search expedition under Sir Edward Belcher passing Cape Lady Franklin, Bathurst Island. Drawing by W.W. May, 1854. Public Archives of Canada.

to Lady Franklin Bay led by Greely in 1881-1883 (Greely 1886).

In 1908-1909, members of J.E. Bernier's expedition aboard the *Arctic*, like Parry's crew before them, spent the winter at Melville Island. Although their observations of wildlife were not extensive, they confirmed earlier speculations that the larger mammals did not leave the islands in winter. Further they found that three species of birds remained there year-round (Bernier 1910).

The International Geophysical Year, 1957-1958

One of the first purely scientific winter studies in the High Arctic was the I.G.Y. party led by C.R. Harington, which conducted studies of weather, lake-ice, and snow conditions at Lake Hazen on northern Ellesmere Island in 1957-1958 (Hattersley-Smith 1974). During the winter, as well as performing other duties, Harington collected information on muskoxen - the basis for the first attempt to synthesize muskox behaviour (Harington 1961).

Recent Overwintering Studies

As part of my long-term study of muskox behaviour, Donald Cockerton and I spent the winter of 1970-1971 at the National Museum of Natural Sciences (NMNS) High Arctic Research Station at Polar Bear Pass on Bathurst Island (Figure 2). Our objectives were to determine what special adaptations to winter conditions were present in the muskox behavioural repertoire, and to assess the accuracy of previous published observations. We also collected weather data and made observations on other wildlife (Gray 1971, 1987).

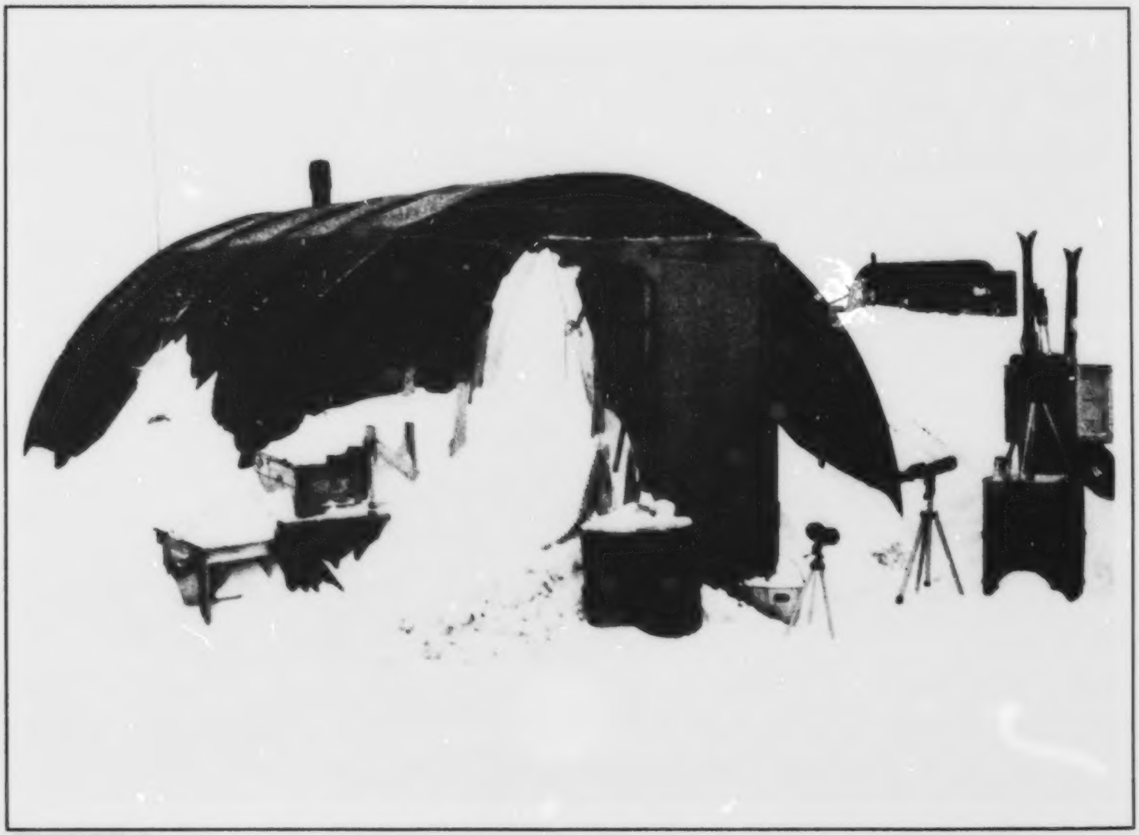


FIGURE 2: Parcoll huts at the NMNS High Arctic Research Station, Bathurst Island, during the winter of 1970-1971. The hut on the left was in use for 12 years.

A third study of muskoxen in winter was carried out in 1972 at the Arctic Institute of North America camp at Truelove Inlet on Devon Island by B.A. Hubert and four companions. Their main goal was to determine productivity of muskoxen. Again, they recorded weather and observations of other species (Hubert 1974, 1977).

Apart from the overwintering at Bathurst Island in 1970-1971, NMNS ethologists have observed the behaviour of arctic animals for a total of 15 months in early and late winter. Recently, Northwest Territories regional biologists stationed in northern communities, have collected more information on winter biology (personal communications, R. Popko, A. Gunn). Thus more data are being recorded on a long-term basis, and there are increased opportunities for conducting winter research.

PRESENT KNOWLEDGE AND GAPS

Birds

Our knowledge of the behaviour and even the presence of the main species of birds that might be expected to spend at least a part of the winter in the Canadian Arctic Islands is limited. From observations made at Bathurst Island (1970-1977), we know that at least 12 of the 30 species which breed in Polar Bear Pass can be seen in September - the start of the winter season. By October, the number is reduced to two species; Rock Ptarmigan, and Snowy Owl. Of the four species expected to spend the winter in the Arctic Islands (Raven, Rock Ptarmigan, Snowy Owl, and Gyrfalcon), we can say that all may winter within their breeding range, but probably in the southern part of that range (Godfrey 1986; Ouellet, this volume). In the 20-year gap between the two editions of "The Birds of Canada" (Godfrey 1966, 1986), so little new information was published on winter behaviour and range that the entries dealing with wintering of these species remain unchanged.

Following is a summary of our knowledge concerning winter survival of the four species in the Arctic Islands.

Raven

This species, which frequents human habitations and their associated refuse dumps, is an obvious possibility for overwintering around arctic settlements. One regularly visited HMS *Hecla* and HMS *Griper* during Parry's stay at Melville Island in the winter of 1819-1820 (Osborn 1856), and Cook (1913) reported Ravens on Devon Island in November and February. Ravens are said to remain on Banks Island year-round (Manning *et al.* 1956).

Rock Ptarmigan

Parry's observations of ptarmigan on Melville Island in February 1820 and Bernier's for 1908-1909 are still the northernmost records of wintering for this species (Godfrey 1986). Greely (1886) saw ptarmigan on northeastern Ellesmere Island in mid-October and in Newman Bay (Greenland) in early March. Our records from Bathurst Island indicate that ptarmigan leave about mid-October, returning in late April or early May. Records of the 1986 Christmas Bird-Count show this species present at Cambridge Bay on Victoria Island in December (personal communication, A. Gunn).

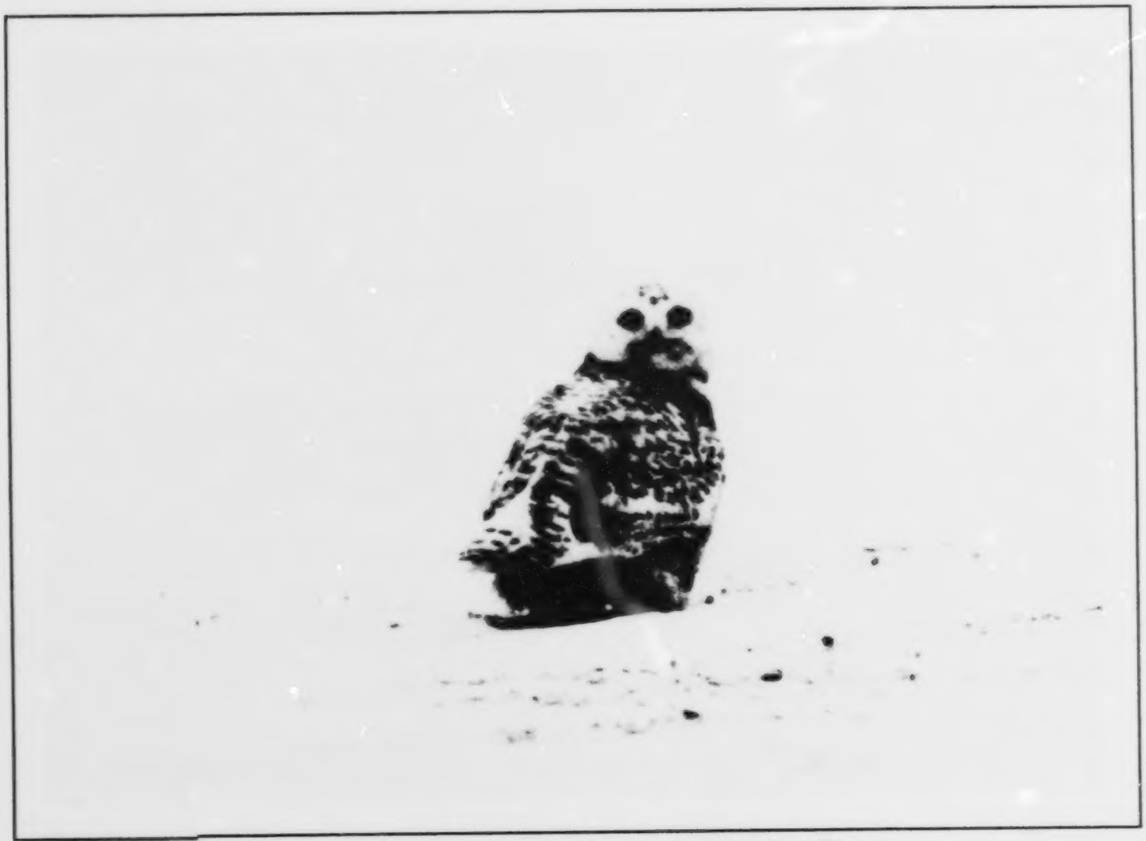


FIGURE 3: Young Snowy Owl at Polar Bear Pass, Bathurst Island, September 30, 1977.

Snowy Owl

Bernier (1910) recorded Snowy Owls throughout the winter on Melville Island. On Victoria Island, they are reported to be present throughout the year, though the highest numbers are seen during the fall migration in October (Smith 1973). On Bathurst Island

Snowy Owls, particularly the young birds, remain throughout September (Figure 3). They are the first species to return in the new year. In 1971, we saw Snowy Owls in late February.

Gyrfalcon

Observations in the fall at several High Arctic localities indicate that Gyrfalcons remain in the Arctic Islands until at least mid-September - in some years well into November. Transient Gyrfalcons were seen near Eureka on Ellesmere Island until mid-September 1955 (Parmelee and MacDonald 1960). MacDonald (personal communication) saw a group of 13 perched on antenna masts at Resolute Bay on 10 November 1954. Indirect evidence (remains of several arctic hares) collected in April 1987 suggests that one or more Gyrfalcons killed hares in Sverdrup Pass, Ellesmere Island after our departure on 9 September 1986 (D.R. Gray, unpublished data). The only mid-winter record for the islands is a white Gyrfalcon collected on Taylor Island (just west of Victoria Island) in January 1918 (Parmelee *et al.* 1967).

Mammals

Arctic Fox

During the winter of 1970-1971 at Polar Bear Pass, foxes were rare, but some (one in particular) were seen frequently throughout September, October, and part of November. Occasionally fresh tracks were observed from December through February. Sightings of at least two individuals increased again in March (Figure 4). The decrease in mid-winter observations supports the idea that foxes spend much time on the sea ice then in search of food left by hunting polar bears (Macpherson 1969; Riewe 1977). Feeding and hunting strategies of individuals in winter will remain unknown until we can follow tagged and radio-collared foxes.

Late winter (mid-February to the end of April) is the arctic fox breeding season (Banfield 1974). We have observed courting pairs on Bathurst and Axel Heiberg islands in late March, and on Ellesmere Island from early to mid-April. The relationship between the timing of the breeding season and available food and weather affecting physical condition is not clear. There is still much to be learned about courtship behaviour - particularly the role of vocalizations.

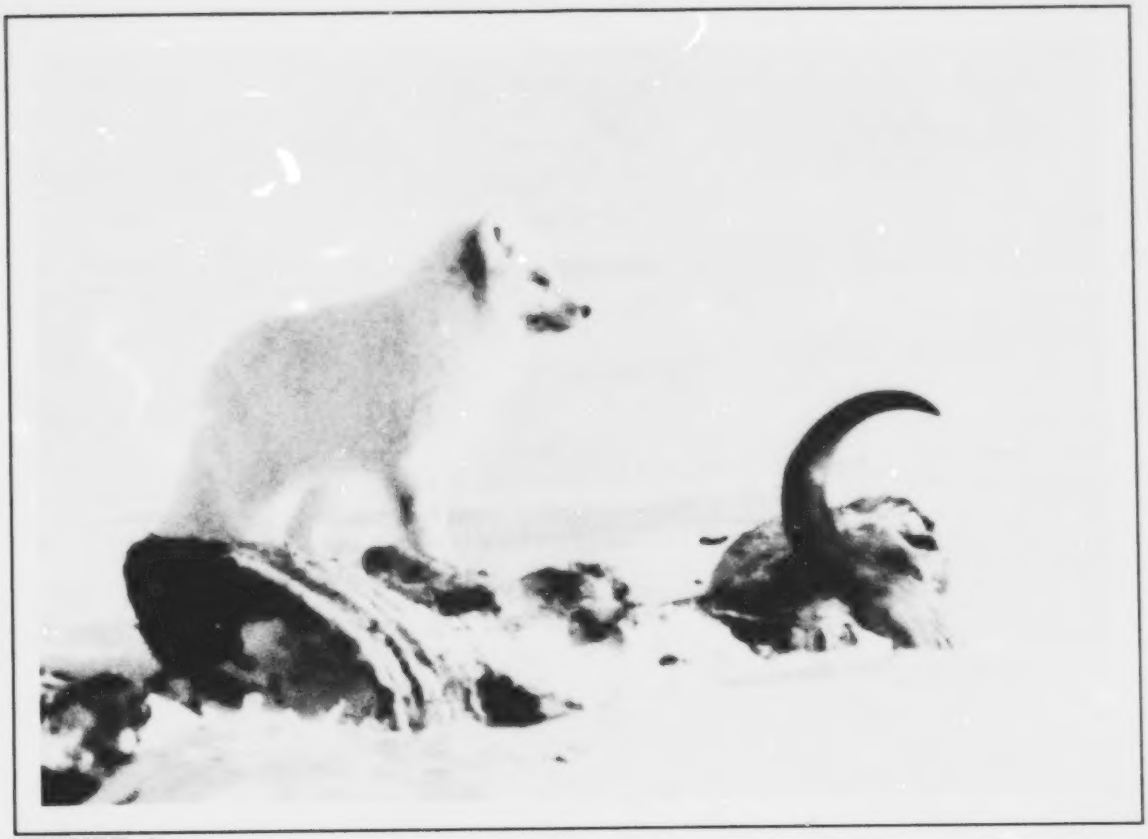


FIGURE 4: Arctic Fox scavenging from wolf-killed muskox carcass.

Arctic Hare

The arctic hare is perhaps one of the poorest known of High Arctic mammals. Greely's observations of hares, their tracks and snow-burrows in December and February were offered as "strong, if not convincing, proof that the animal does not hibernate". Our recent long-range studies have only begun to build on some intriguing observations made by early arctic explorers (Gray and Hamilton 1982; Aniśkowicz *et al.*, this volume). Parker (1977) investigated several aspects of hare biology, including the reproductive status of males and females, in March on Axel Heiberg Island.

My study of hare behaviour, begun in 1985 at Sverdrup Pass on Ellesmere Island, includes a detailed analysis of courtship behaviour in groups and in single pairs in April-May (D.R. Gray, unpublished data). Late winter studies begun in 1969 at Polar Bear Pass, where the hare population is scattered and small but predictable in terms of location, are concentrating on the use of snow-dens by hares during late winter. Snow-dens are known from several localities but no significant new information on their use has been published since Fielden's (1877B) description.

Arctic Wolf

The nature of the wolf and its environment account for the great gaps in our knowledge of this species. Studies of arctic wolves in Canada have been limited to incidental observations made while studying other species (Riewe 1975), observations at dump sites near weather stations (Grace 1976), and studies relating wolf behaviour to that of their prey (Gray 1983).

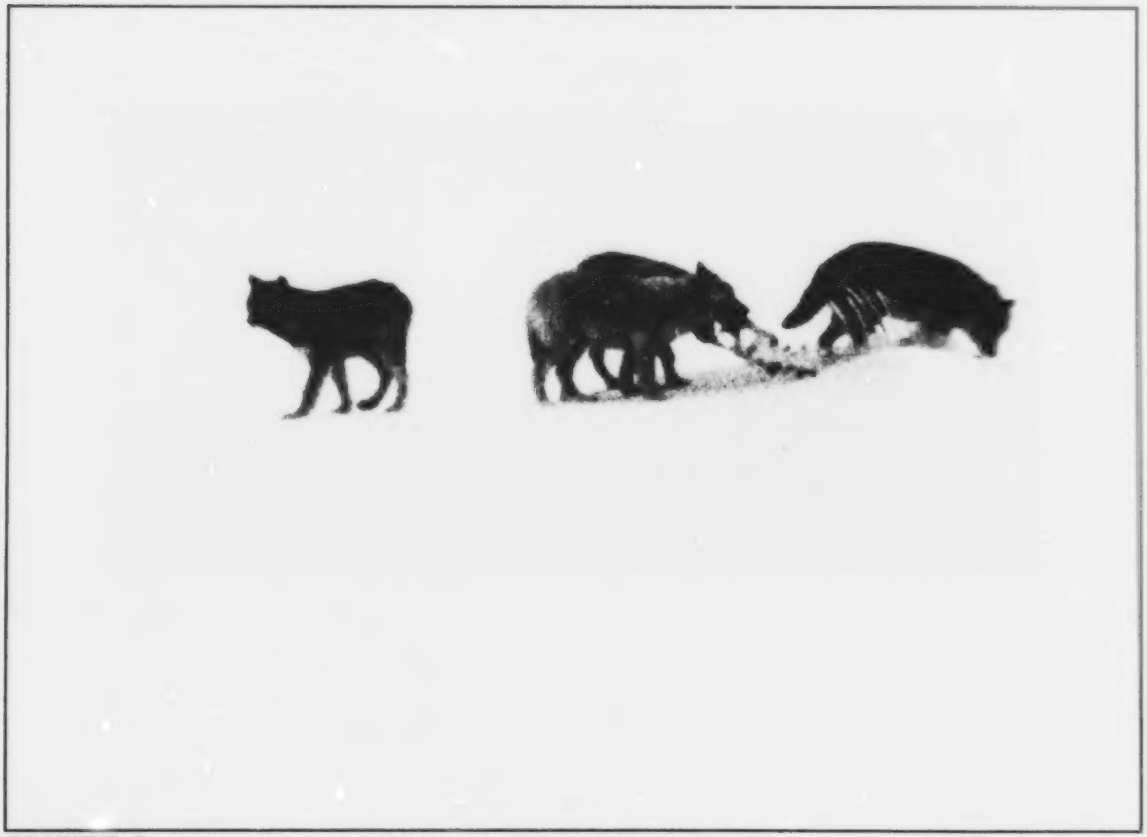


FIGURE 5: Wolf pups investigating an old muskox skeleton, September 28, 1977.

The presence of the High Arctic Research Station on Bathurst Island over many years has meant that substantial data on wolf behaviour in winter have accumulated. Wolves were observed at intervals throughout the winter of 1970-1971, and we watched them kill two muskoxen in March (Gray 1987). In September 1977, the activities of a pack of 10, including five pups, centred on our study area. In a 20-day period, we recorded 13 hunts, five interactions with muskoxen, and two kills. As well as learning much about the behaviour of the pups (Figure 5), we found that muskox kills were used as rendezvous for the pups when the adults left on hunting trips (D.R. Gray, unpublished data).

A recent study of the behaviour of a wolf pack at a den near one of the arctic weather stations on Ellesmere Island (Mech 1987) is expected to continue, and the observation period is to be expanded into the late winter months and the period of courtship (Mech 1988). With Mech's experience in the use of radio-tracking techniques, this study has great potential for expanding our knowledge of wolf behaviour in winter. I hope that the pursuit of photographs will not limit the potential for marking and tracking individuals.

Lemming

That lemmings are active beneath the winter snow is well known. The extent of their surface activities in mid-winter is less clear. While travelling between the Arctic Islands in mid-April 1929, Joy saw great numbers of lemming tracks on the sea ice and even on icebergs, sometimes more than a day's journey from land (Royal Canadian Mounted Police 1929). On Bathurst Island, lemmings or their tracks were seen above ground regularly between September and March. In February 1971, tracks of an individual were followed across the snow for at least of 500 m. Data on population fluctuations in relation to burrow availability and weather conditions, as well as studies of snow depths and temperatures at winter nesting areas, indicate that lemming population fluctuations are far from predictable or cyclical (D.A. Gill, unpublished data).

Muskox

Despite three winter studies and several investigations in early or late winter, our knowledge of muskoxen is still far from complete. These studies have clarified winter feeding behaviour and energy demands (Gray 1987, Hubert 1977), the relationship with wolves as major predators (Gray 1983), and the behaviour of muskoxen during winter storms (Gray 1987) (Figure 6). Unfortunately the results of these studies are still not widely known and the popular literature dealing with muskoxen still uses faulty and out-of-date information.

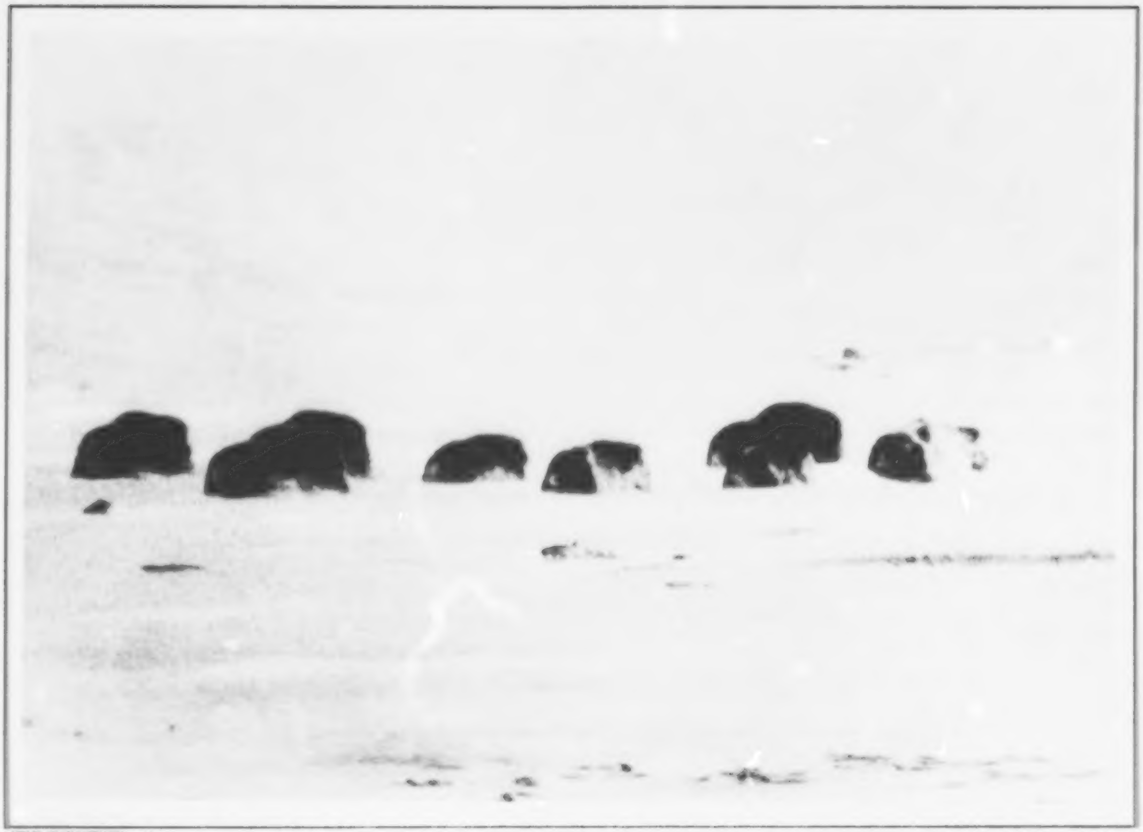


FIGURE 6: At the end of a late winter blizzard on Ellesmere Island, a herd of muskoxen remains lying down, some individuals partially covered by drifting snow.

Perhaps the most frustrating example to me is continued use of the story that muskoxen form a defense circle with adult males on the outside and females and young at the centre, not only when faced by wolves but also during winter blizzards. This misconception, apparently based on Pedersen (1958), still appears in general texts, children's books, and more seriously, in new mammal books and even respected journals. Another aspect of late winter about which we need more information is the weaning of calves ("short yearlings") before the birth of the new calves in mid-April or later. Young muskoxen continue to suckle as yearlings if a new calf is not born in the spring. On Bathurst Island we have observed yearlings suckling in October at about 18-months old. However, we know nothing about the timing of weaning when the calf's mother is pregnant. Observations at Sverdrup Pass of yearlings accompanying pregnant cows suggest that weaning occurs during the winter as no suckling attempts were seen in April.

Peary Caribou

This is only arctic land mammal officially declared endangered. It is also the poorest known form of caribou. Canadian Wildlife Service studies (Miller *et al.* 1977; Miller, this volume; Parker *et al.* 1975) have shown the seriousness of the problem at a population level. Observations at Polar Bear Pass have also indicated gaps in our knowledge. In September, small herds of caribou cross the pass to wintering areas thought to be in the southwestern part of the island. Males are in the rut then but little is known of their behaviour. Further, we lack information on the nature of their northward movements and the calving-grounds. Our observations indicate that caribou were a significant prey species for wolves before the population decline of 1973-1974 (Figure 7). The role of wolf predation in the slow recovery since then is unknown.

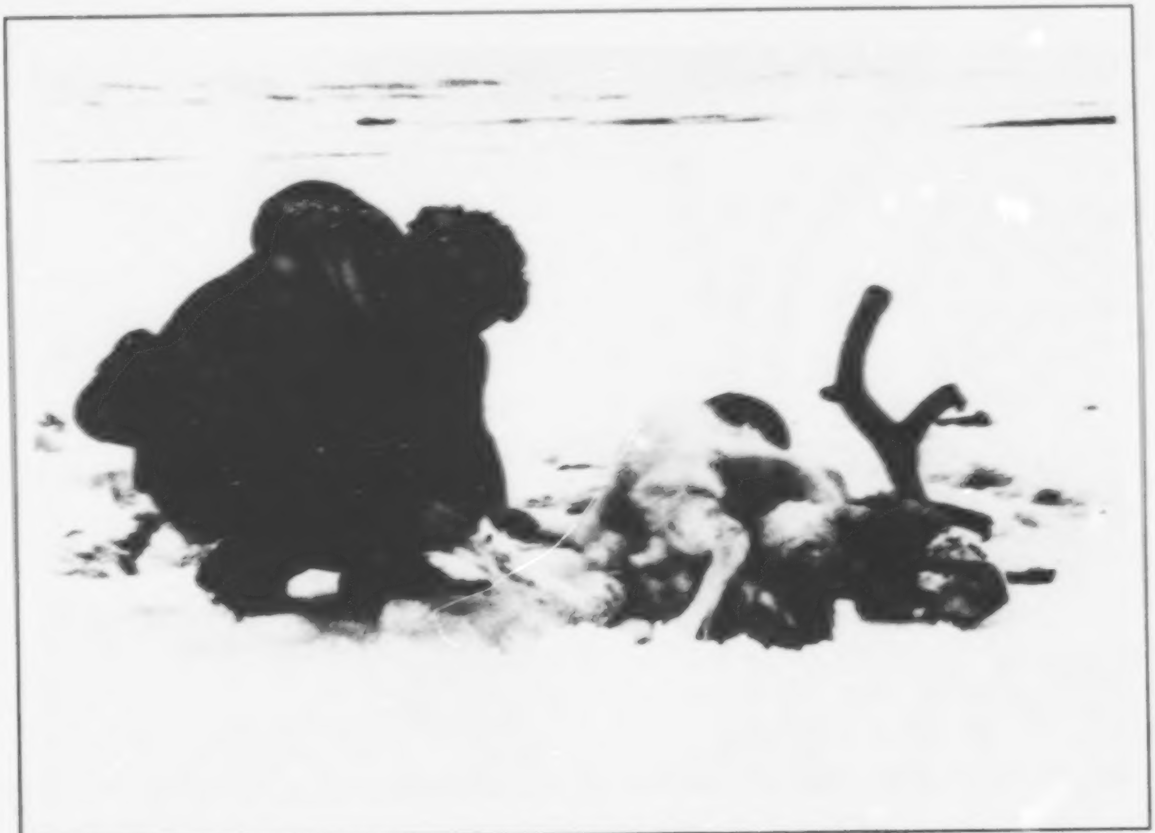


FIGURE 7: David Gray examining the carcass of a bull Peary caribou killed by wolves in Polar Bear Pass.

Ermine

Winter activities of ermine are directly tied to those of the lemming. Ermine were not seen during winter studies at Bathurst Island, though they were common there in some summers. Riewe (1977) found several ermine tracks on Devon Island in February and March 1971, and also in September and early October. Based on spring observations of lemming winter nests, predation was common, but the under-snow behaviour in relation to that predation is a mystery.

Wolverine

The presence of the wolverine in the High Arctic in winter (or at any time) is doubtful. Although distribution maps in general texts routinely show the wolverine to be present on most of the northern islands (e.g. Banfield 1974), the only records are a sighting on Little Cornwallis Island in 1961 (Tener 1963) and a cranium found on Melville Island in 1819 (Fisher 1821). The species is rare and may not have resident populations in the High Arctic islands (van Zyll de Jong 1975).

Marine Animals

Though marine mammals (including polar bears) and seabirds are beyond the scope of this paper, I would like to acknowledge the work of several investigators who have made significant contributions to our knowledge of seabirds and marine mammals in winter, especially Gaston and Nettleship (1981), Harington (1968), Stirling and his associates (Kiliaan and Stirling 1978; Calvert and Stirling 1985), and Smith and Memogana (1977). Work on the significance of polynyas to winter birds and mammals is of particular importance (Stirling and Cleator 1981).

PROBLEMS AND SOLUTIONS

Environmental and logistical problems of studying birds and mammals in the Canadian Arctic Islands in winter are obvious - intense cold, low light-levels , ice fog, as well as problems of establishing and supplying a camp, transportation, and choosing suitable personnel.

Environment

Although studying animals in the High Arctic in winter will never be easy, some recent developments have changed the situation for the better. In 1970, when we attempted to watch muskoxen during the dark period, special equipment that would have made those studies more successful, such as night vision scopes and radio telemetry were beyond reach of our budget and, at the same time, too cumbersome to be of much practical value. Today such equipment is readily available, less expensive, and much more efficient. The period of winter "darkness" is not as impeding as many think. The long periods of twilight together with the moonlight provide many hours each month that could be suitable for travel and observation.

Coping with the cold is another area where high technology clothing has made a great difference, though I consider traditional Inuit clothing to be superior to the modern.

Logistics

The excellent logistical support offered to researchers by the Polar Continental Shelf Project (Hobson, this volume) means that the necessary field support is available at both ends of the winter, since Polar Shelf usually opens its Resolute base in February or March and closes in September. Unfortunately, in years when there are no major winter projects, the base may open only at winter's end and close before winter settles in. Safe operation of aircraft using off-strip landings restricts the non-wintering biologist to the period before November and after February, depending on location.

The establishment of permanent field research stations at several places in the Arctic Islands means that winter studies can occur without a great expenditure of time and resources. For example, the National Museum of Natural Sciences and the Arctic Institute of North America encourage the use of their research stations, on Bathurst and Devon islands respectively, by other researchers (especially university students) as long as the work conforms to station policy.

In spite of the deplorable reduction in the number of arctic weather stations, these long-established bases still offer unique opportunities as centres for winter biological studies. In the early days of arctic biological investigation these weather stations were of great importance as the only "permanent" bases for field work (MacDonald 1952, 1961).

With regard to the policy of establishing large government research stations in northern communities (e.g. Igloolik and Inuvik), I agree with the assessments of Hattersley-Smith (1974) and Tener (1982) that such a policy is of limited use in terms of biological science. There is usually little or no wildlife within a great distance of these settlements, and the expenditure of similar funds on smaller, remote permanent stations or portable, temporary stations would yield far greater returns for money spent. To make significant progress we do not require elaborate quarters. We could easily get by on the level of accommodation provided to explorers 100 years ago (Figure 8). Our experiences with the versatile and portable Parcoll huts under extreme winter conditions have demonstrated that all one really needs for winter study accommodation is a three- or four-section Parcoll for a two-person team.

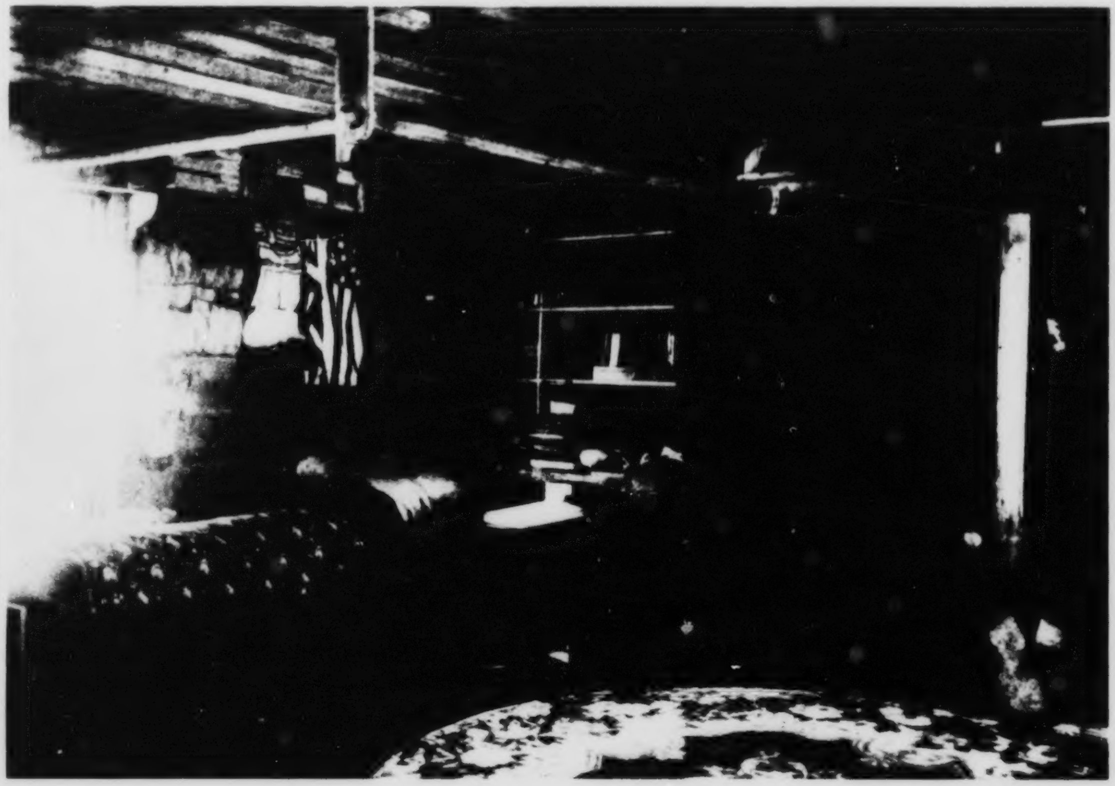


FIGURE 8: Greely's corner at Fort Conger, Ellesmere Island, October 1881 (Public Archives of Canada, C-5499).

Cooperation

If we are to greatly advance our knowledge of arctic animals in winter, we will have to exploit cooperative programs. Cooperation with oil exploration companies, for example, has led to new sources of funds, logistic support and even new data. With the expansion of the Northwest Territories Renewable Resources regional biologist program to more communities, there are increasing opportunities for joint research projects.

An area of potential cooperation that, in my experience, has proved to be mostly negative, is with the Canadian Armed Forces (Editor's note: but see Morrison and Davidson, this volume). On Bathurst Island in past years, and recently on Ellesmere Island, CAF helicopters have repeatedly interfered with research programs and harassed animals under study. Perhaps with a new command structure in the northern region and better communication, this situation can be changed to benefit northern science.

Above all, cooperation between northern biologists and the Inuit is important. Inuit hunters in particular have contributed a great deal to polar bear (Harington 1968) and marine mammal (Smith 1977) studies. The hunters' knowledge of birds and mammals, particularly prey species should be better used and recorded. Observations made during winter hunts have provided much interesting data that would be difficult to obtain by professional biologists, as Gunn, Arlooktoo and Kaomayok (1988) have indicated. By participating in the regular winter muskox hunts on Ellesmere Island, Rowell (1980) was able to collect rare and useful data on muskox reproduction.

THE FUTURE

It seems likely that most future studies involving an overwintering period will, as in the past, be done by university students on thesis projects. The length of time required to obtain sufficient data and the length of a winter make footloose graduate students ideal for this work. Programs initiated by the Northern Heritage Foundation (McCreadie 1987) will help ensure that northerners will be able to take part in future winter studies.

It is encouraging to note that several winter-oriented studies by students are underway presently. Martin Raillard (personal communication) is investigating the effect of winter grazing of muskoxen on plant communities at Sverdrup Pass; Becky Sjare (personal communication) will study winter behaviour of walruses, and Ursula Peterson (personal communication) is collecting information on Snowy Owl migrations and winter habits in the North.

As this volume is intended to provide ideas for future research planning in the Canadian Arctic Islands, and originated through the National Museum of Natural Sciences, it is appropriate to consider future programs of NMNS vertebrate ethologists, and the High Arctic Research Station at Bathurst Island in relation to winter research.

We intend to operate the Bathurst Island station at current levels for the next five years, or at least until the level of protection for the Polar Bear Pass National Wildlife Area has been established. At present, a wooden laboratory building with a small observation tower, and a Parcoll hut are the station's nucleus. Two Parcoll hut frames are standing and can be used when needed.

Necessarily, biological research at the station has focused on the summer season, in order to understand the breeding behaviour and ecology of migratory birds. However, valuable data for both bird and mammal studies have come from the time spent there during, and at both ends of, the winter. It is important to continue and expand our early and late winter observations.

Thus, future NMNS research projects will include the arctic hare behavioural study, particularly breeding behaviour and the use of snow-dens in late winter. Wolf studies at Bathurst Island will continue as opportunities permit, especially on feeding behaviour and predation in relation to the island's population of endangered Peary caribou. Surveys near a possible den site in the National Wildlife Area will continue.

Bird studies will concentrate on the early and late winter behaviour of several migratory bird species. As part of this project, the bird-banding program begun in 1968 will be continued, and in relation to it, information on winter behaviour of birds will be collected from various sources.

It is clear from this review that our knowledge of birds and mammals in the Canadian Arctic Islands in winter is inadequate. It is also evident that more information exists (in unpublished form): (1) at Inuit communities; (2) in the records of Northwest Territories regional biologists; (3) in incidental observations of weather station personnel and the Royal Canadian Mounted Police. These sources, and some of the more obscure records of early explorers, will have to be better used to increase our understanding of Canada's North.

As Roots (1969) has suggested, one has to be generous and assume that the lack of winter investigations is due to the increased costs and difficult logistics of winter work rather than the discomforts. In the report, "Canada and Polar Science", Adams *et al.* (1987) stressed the serious effect of current funding restrictions on arctic biology - even the essential work carried out by small parties using simple methods. It is precisely this kind of research that the NMNS is best equipped to carry out. I hope that those responsible for securing adequate support for arctic scientists can work with them to achieve an acceptable level of knowledge of the fauna of the Canadian Arctic Islands.

ACKNOWLEDGEMENTS

I acknowledge the support and encouragement given to me during my own winter studies by S.D. MacDonald and E.F. Roots. Logistic support for winter work by the Vertebrate Ethology Section of the National Museum of Natural Sciences continues to be generously provided by the Polar Continental Shelf Project. I also thank David A. Gill for his contribution to this paper and the NMNS High Arctic research programs. Others who helped me collect winter data were: Donald Cockerton, John Morgan, Richard Popko, Looty Pijamini, Janice Rowell, and Thomas Sadler. Anne Gunn provided unpublished data on winter observations and on the subject of the contribution to research by Inuit hunters.

REFERENCES

Adams, W.P., P.F. Burnet, M.R. Gordon, and E.F. Roots. 1987. Canada and polar science. Indian and Northern Affairs Canada, Ottawa. 129 pp.

Banfield, A.W.F. 1974. The mammals of Canada. University of Toronto Press. Toronto. 438 pp.

Bernier, J.E. 1910. Report on the Dominion of Canada Government Expedition to the Arctic Islands and Hudson Strait on board the D.G.S. *Arctic*. Government Printing Bureau. Ottawa. 529 pp.

Calvert, W. and I. Stirling. 1985. Winter distribution of ringed seals (*Phoca hispida*) in the Barrow Strait area, Northwest Territories, determined by underwater vocalizations. Canadian Journal of Fisheries and Aquatic Sciences 42(7):1238-1243.

Cook, F.A. 1913. My attainment of the Pole. Mitchell Kennerley, New York and London. 610 pp.

Fielden, H.W. 1877A. List of birds observed in Smith Sound and in the Polar Basin during the Arctic Expedition of 1875-76. Zoologist, Series 4, 1:401-412.

______. 1877B. On the Mammalia of North Greenland and Grinnell Land. Zoologist, Series 3, 1:313-321, 353-361.

Fisher, A. 1821. Journal of a voyage of discovery to the Arctic regions, in His Majesty's Ships *Helca* and *Griper*, in the years 1819 and 1820. Longmans, Hurst, Rees, Orme and Brown, London.

Gaston, A.J. and D.N. Nettleship. 1981. The Thick-billed Murres of Prince Leopold Island, a study of the breeding ecology of a colonial High Arctic seabird. Canadian Wildlife Service, Monograph Series, Number 6:1-350.

Godfrey, W.E. 1966. The birds of Canada. National Museum of Canada, Bulletin 203. Ottawa. 428 pp.

______. 1986. The birds of Canada. Revised edition. National Museum of Natural Sciences, Ottawa. 595 pp.

Grace, E.S. 1976. Interactions between men and wolves at an arctic outpost on Ellesmere Island. Canadian Field-Naturalist 90(2):149-156.

Gray, D.R. 1971. Winter research on the muskox (*Ovibos moschatus*) on Bathurst Island, 1970-71. Arctic Circular 21(3):158-163.

______. 1977. The status of the muskox and Peary caribou on Canada's Arctic Islands. In: Canada's Threatened Species and Habitats. Edited by: T. Mosquin and C. Suchal. Canadian Nature Federation, Special Publication 6:57-62.

______. 1983. Interactions between wolves and muskoxen on Bathurst Island, N.W.T., Canada. Acta Zoologica Fennica 174:255-257.

______. 1987. The muskoxen of Polar Bear Pass. National Museum of Natural Sciences, and Fitzhenry and Whiteside, Toronto. 192 pp.

Gray, D.R. and H. Hamilton. 1982. Hare revelations: the bizarre behaviour of the arctic hare. Nature Canada 11(1):48-54.

Greely, A.W. 1886. Three years of arctic service. Volume 2. Charles Scribner's Sons, New York. 444 pp.

Gunn, A., G. Arlooktoo, and D. Kaomayok. 1988. The contribution of the ecological knowledge of Inuit to wildlife management in the Northwest Territories. In: Wildlife and Native People. Edited by: L. Carbyn and M.M.R. Freeman. Boreal Institute, Occasional Papers 23.

Harington, C.R. 1961. History, distribution and ecology of the muskoxen. M.Sc. thesis. McGill University, Montreal. 489 pp.

______. 1968. Denning habits of the polar bear (*Ursus maritimus* Phipps). Canadian Wildlife Service, Report Series 5:1-30.

Hattersley-Smith, G. 1974. North of Latitude Eighty. Defence Research Board, Ottawa. 121 pp.

Hummel, M. 1984. Arctic wildlife. Key Porter, Toronto. 160 pp.

Hubert, B.A. 1974. Estimated productivity of muskox on northeastern Devon Island. M.Sc. thesis, University of Manitoba, Winnipeg. 118 pp.

______. 1977. Estimated productivity of muskox on Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 467-491.

Kiliaan, H.P.L. and I. Stirling. 1978. Observations on overwintering walruses in the eastern Canadian High Arctic. Journal of Mammalogy 59:197-200.

MacDonald, S.D. 1952. Report on biological investigations at Mould Bay, Prince Patrick Island, N.W.T., in 1952. Annual Report, National Museum of Canada, 1952-53, Bulletin 132:214-238.

______. 1961. Biological investigations at Isachsen, Ellef Ringnes Island, N.W.T. National Museum of Canada, Bulletin 172:90-97.

______. 1980. Scientific progress: terrestrial biology, an overview. In: A Century of Canada's Arctic Islands, 1880-1980. Edited by: M. Zaslow. Royal Society of Canada. pp. 171-186.

Macpherson, A.H. 1969. The dynamics of Canadian arctic fox populations. Canadian Wildlife Service, Report Series 8:1-52.

Manning, T.H., E.O. Hohn, and A.H. Macpherson. 1956. The birds of Banks Island. National Museum of Canada, Bulletin 143:1-144.

McCreadie, M. 1987. Financial aid for northern scientific assistants: the Northern Heritage Society and the Science Institute of the Northwest Territories collaborate. In: The Canadian Arctic Islands: Canada's Missing Dimension. Program and Abstracts. p. 105.

Mech, L.D. 1987. At home with the arctic wolf. National Geographic 171(5):562-593.

Mech, L.D. 1988. Ellesmere Island; life in the High Arctic. National Geographic 172(6):750-767.

Miller, F.L., R.H. Russell, and A. Gunn. 1977. Distributions, movements and numbers of Peary caribou and muskoxen on western Queen Elizabeth Islands, Northwest Territories, 1972-74. Canadian Wildlife Service, Report Series 40:1-55.

Osborn, S. 1856. The discovery of a North-West Passage by H.M.S. *Investigator*, Capt. R. M'Clure, during the years 1851, 1852, 1853, 1854. William Blackwood and Sons, London. 358 pp.

Parker, G.R. 1977. Morphology, reproduction, diet, and behaviour of the arctic hare (*Lepus arcticus monstrabilis*) on Axel Heiberg Island, Northwest Territories. Canadian Field-Naturalist 91(1):8-18.

Parker, G.R., D.C. Thomas, E. Broughton, and D.R. Gray. 1975. Crashes of muskox and Peary caribou populations in 1973-74 on the Parry Islands, Arctic Canada. Canadian Wildlife Service, Progress Notes 56:1-10.

Parmelee, D.F. and S.D. MacDonald. 1960. The birds of west-central Ellesmere Island and adjacent areas. National Museum of Canada, Bulletin 169:1-103.

Parmelee, D.F., H.A. Stephens, and R.H. Schmidt. 1967. The birds of southeastern Victoria Island and adjacent small islands. National Museum of Canada, Bulletin 222:1-229.

Pedersen, A. 1958. Der Moschusochs (*Ovibos moschatus* Zimmermann). A. Ziemsen Verlag, Wittenberg. 54 pp.

Riewe, R. 1975. The High Arctic wolf in the Jones Sound region. Arctic 28:209-212.

______. 1977. Mammalian carnivores utilizing Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. 714 pp.

Roots, E.F. 1969. The role of logistics in northern research. In: Proceedings of the Second National Northern Research Conference. Edited by: J.J. Bond. Boreal Institute, Edmonton. pp. 65-77.

______. 1987. The natural realm and arctic heritage. In: Arctic Heritage, Proceedings of a Symposium. Association of Colleges and Universities for Northern Studies. Ottawa. pp. 164-176.

Rowell, J. 1980. A preliminary study of the reproductive anatomy of the female muskox (*Ovibos moschatus*). M.Sc. thesis, University of Ottawa. Ottawa. 190 pp.

Royal Canadian Mounted Police. 1929. Report of the Royal Canadian Mounted Police for the year ended 30 September, 1929.

Smith, T.G. 1973. The birds of the Holman Region, western Victoria Island. Canadian Field-Naturalist 87(1):35-42.

Smith, T.G. and J. Memogana. 1977. Disorientation in ringed and bearded seals. Canadian Field-Naturalist 91(2):181-182.

Stirling, I. and H. Cleator. 1981. Polynyas in the Canadian Arctic. Canadian Wildlife Service, Occasional Papers 45:1-73.

Tener, J.S. 1963. Queen Elizabeth Islands Game Survey, 1961. Canadian Wildlife Service, Occasional Papers 4:1-50.

______. 1982. Arctic biology. Transactions of the Royal Society of Canada 20:429-434.

van Zyll de Jong, C.G. 1975. The distribution and abundance of the wolverine (*Gulo gulo*) in Canada. Canadian Field-Naturalist 89(4):431-437.

Illustrated by Brenda Carter

THE DECLINE AND RECOVERY OF CARIBOU AND MUSKOXEN ON VICTORIA ISLAND

Anne Gunn[1]

Abstract: Numbers of caribou and muskoxen on Victoria Island reached a low between the 1920s and the 1930s. The Dolphin-Union caribou herd which used to migrate seasonally between southern Victoria Island and the mainland had disappeared. The causes of the decline and the slow recovery are difficult to confirm, but hunting and severe winters were factors. It was not until the 1970s that hunters began to report increases in muskox and caribou numbers, and both species have recolonized southern Victoria Island. The decrease and increase in the numbers of muskoxen and caribou is consistent with trends elsewhere in the Northwest Territories. In Greenland, similar cyclic fluctuations in wildlife are suggested to be responses to climatic changes. The Kitikmeot Hunter's and Trapper's Association harvest study documents the continued importance of caribou hunting to the communities of Holman and Cambridge Bay. The commercial use of muskoxen and caribou is rising as guided non-resident hunting and commercial meat sales increase. The Government of the Northwest Territories' emphasis on development of the renewable resource economy highlights the need to understand the numbers of caribou and muskoxen in relation to climatic changes.

Résumé: La population de caribous et de boeufs musqués de l'île Victoria a atteint un minimum dans les années 1920 et 1930. La harde de caribous de Dolphin et Union qui avait l'habitude de migrer entre le sud de l'île Victoria et le continent avait disparu. Les raisons qui pourraient expliquer cette baisse et cette lente remontée sont difficiles à prouver, mais on croit que la chasse et les hivers rigoureux ont pu être des causes. Ce n'est que vers les années 1970 que des chasseurs ont commencé à signaler des augmentations du nombre de caribous et de boeufs musqués et que ces deux espèces ont repeuplé le sud de l'île Victoria. La diminution et l'augmentation du nombre de caribous et de boeufs musqués correspondent à des variations qu'il y a ailleurs dans les Territoires du Nord-Ouest. Au Groënland, on retrouve ces mêmes variations cycliques de la faune qui résultent probablement de changements climatiques. L'étude sur la récolte des caribous faite par la Kitikmeot Hunter's and Trapper's Association confirme l'importance de la chasse au caribou pour les collectivités de Holman et de Cambridge Bay. La chasse avec guide des non-résidents de l'Arctique et les ventes de viande font augmenter l'usage commercial que l'on fait des caribous et des boeufs musqués. L'accent que met le gouvernement des Territoires du Nord-Ouest sur le développement d'une économie basées sur des ressources renouvelables souligne la nécessité de bien établir le lien qui existe entre, d'une part, la population de caribous et de boeufs musqués et, d'autre part, les changements de climat.

INTRODUCTION

The numbers of caribou (*Rangifer tarandus* spp.) and muskoxen (*Ovibos moschatus*) on Victoria Island decreased from the end of the nineteenth century, and remained low until the 1970s. The evidence for the decline and subsequent recovery mostly comes from Inuit oral history and hunters' recent observations. Scientific studies of wildlife were few until the mid-1980s.

Europeans rarely visited Victoria Island until the establishment of trading posts in the 1920s. Its rather central geographic location among Canada's Arctic Islands virtually isolated it from the early probes for the North-West Passage, searches for the Franklin Expedition, exploration for the North Pole and whaling. Further, the relative lack of commercially valuable hydrocarbons and minerals left Victoria Island without the environmental studies spawned by industrial exploration and development elsewhere in the Arctic Islands.

---

[1] Department of Renewable Resources, Government of the Northwest Territories, Coppermine, Northwest Territories X0E 0C0

The virtual isolation of Victoria Island from scientific studies hampers any reconstruction of fluctuations in wildlife numbers. An understanding of population changes would be a sound basis for future wildlife management. Victoria Island is the second largest of the Canadian Arctic Islands and the southernmost of the larger western islands. Sustained use of its natural resources could play a significant role in fostering the continued occupation and development of the islands.

This paper describes the evidence for fluctuations in numbers of caribou and muskoxen from anthropological and wildlife sources. I speculate on the causes of the changes in numbers and their implications for future management of caribou and muskoxen.

MATERIALS AND METHODS

I drew heavily on the Inuit Land Use and Occupancy Project (Freeman 1976) for information on the prehistory and history of the human occupation of Victoria Island. I supplemented this information with other references and the personal recollections of local people from Coppermine, Holman and Cambridge Bay. Other wildlife data are from: published papers; unpublished reports in the files of Canadian Wildlife Service and Northwest Territories Wildlife Service (now the Department of Renewable Resources); unpublished reports of consultants for the Polar Gas Project; and studies currently underway, including the Kitikmeot Harvest Study.

RESULTS

Archaeological Information

The archaeological record for Victoria Island is too sparse in time and space to evaluate the status of either caribou or muskoxen. Southern and western coasts were occupied during pre-Dorset, Dorset and Thule times (McGhee 1976). Bones from those sites reveal the presence and the use of both caribou and muskoxen.

Anthropological Information

Pre-trading Era

People living along the south coast of Victoria Island (Freeman 1976) moved to the coast in fall to intercept groups of caribou gathering to cross to the mainland once the sea ice had formed. In April, people moved from sealing camps on the ice to the coast to hunt the returning caribou. Farther north, three Inuit groups that would eventually settle in Holman also relied on caribou. In the fall, Inuit hunted caribou along the northern margin of Minto Inlet and Prince Albert Sound. In spring, caribou and muskoxen were hunted northward toward Richard Collinson Inlet and Glenelg Bay (Figure 1).

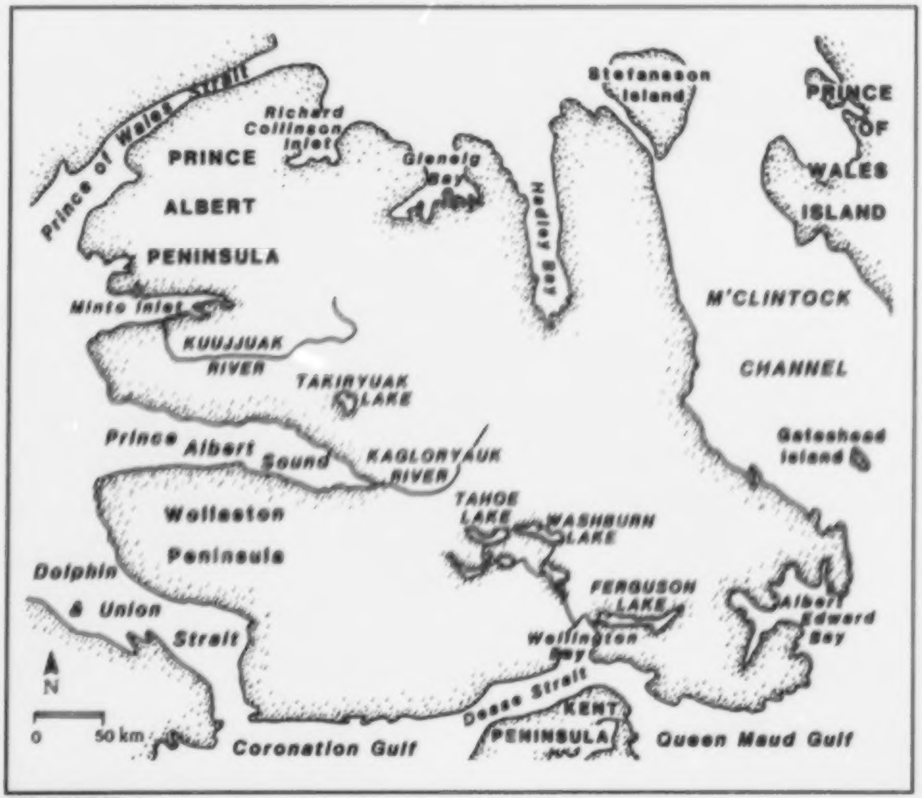

Prince of Wales Strait
Richard Collinson Inlet
PRINCE ALBERT PENINSULA
Glenelg Bay
Stefansson Island
Hadley Bay
PRINCE OF WALES ISLAND
M'CLINTOCK CHANNEL
Minto Inlet
KUUJJUAK RIVER
TAKIRYUAK LAKE
Prince Albert Sound
KAGLORYAUK RIVER
Gateshead Island
TAHOE LAKE
WASHBURN LAKE
Wollaston Peninsula
Dolphin & Union Strait
FERGUSON LAKE
Albert Edward Bay
Wellington Bay
Dease Strait
KENT PENINSULA
Queen Maud Gulf
Coronation Gulf
N
0
50 km

FIGURE 1: Place names on Victoria Island mentioned in text.

On eastern Victoria Island, people depended more on sealing and fishing. Hunters had to travel long distances to the vicinity of Hadley Bay for caribou. The area north of Albert

Edward Bay toward Gateshead Island was known for muskoxen. People on southeastern Victoria Island hunted caribou that migrated between the island and the mainland in spring and fall.

Manning (1960) compiled historical information on numbers of caribou involved in the migrations between the island and the mainland. There is virtually no information on the caribou populations that were resident on the island during the winter (Manning 1960). Eye-witness accounts, and extrapolation based on the area of Victoria Island, led Manning (1960) to suggest that some 111,000 caribou spent the summer on Victoria Island before the 1920s.

Trading Era

Introduction of rifles extended the hunting seasons for caribou to the winter. The shift from a hunting to a hunting and trapping lifestyle increased the travelling in winter as trap-lines grew in length. Consequently, the trappers needed larger dog-teams and more dog food. The location of winter camps shifted from the sea ice of Dolphin and Union Strait and Coronation Gulf to permanent camps along the southern coast of Victoria Island. Travel inland for caribou and fish during the summer decreased in favour of hunting and caching seals along the coast for dog food.

The pattern of caribou hunting on Victoria Island changed after the opening of trading posts. The first trading posts in the area were established in 1916 at Bernard Harbour, Banks Island and at Rymer Point on Victoria Island in 1919. Trading ships had preceded the trading posts - for example Klengenberg wintered on southwestern Victoria Island in 1905-1906 and Mogg at Walker Bay in 1907-1908. The migration of caribou across Dolphin and Union Strait and Coronation Gulf ceased a few years after the establishment of the trading posts on the southwestern coast of Victoria Island and along the western mainland coast (Manning 1960; Freeman 1976). The migration of caribou from Kent Peninsula across Dease Strait to near Byron Bay stopped about 1930 (Freeman 1976).

The loss of the Dolphin and Union herd that had migrated across Wollaston Peninsula, and possibly as far north as Minto Inlet, left those areas without caribou. People from the Prince Albert Sound and Minto Inlet areas switched to hunting the resident Victoria Island caribou farther north and inland toward Shaler Mountains. Other people from the Read Island area either moved to the mainland or made trips to hunt caribou on the mainland.

The people on eastern Victoria Island continued to travel widely to hunt resident Victoria Island caribou or to the mainland. Many of the recollections of people about changes in hunting after the establishment of trading posts refer to caribou being considered scarce during the 1940s and early 1950s (Freeman 1976). Muskoxen were scarce from at least 1923 to 1939 near Minto Inlet, where they had been hunted previously. Muskox hunting areas contracted during the same period on southeastern Victoria Island, but there are few details on the reduction of muskoxen. Stefansson (1923) recounted that in 1911, Eskimos at Prince Albert Sound believed muskoxen were almost extinct in the area, which suggests muskoxen declined before caribou.

The scarcity of caribou and muskoxen until the 1960s is illustrated by some hunters' comments. D. Komoayok (personal communication) tells of how once hunters crossed a caribou trail, they would track it for days, if necessary, to kill it. Other hunters had to travel to the mainland for caribou meat and hides. Hunters recollect that it was not until the 1960s or even early 1970s when they saw the first muskoxen north of Cambridge Bay.

Wildlife Surveys

Wildlife surveys were not undertaken on Victoria Island until 1979, but A.H. Macpherson (1960 unpublished report, Canadian Wildlife Service) compiled the wildlife observations of geologists during extensive (18,400 km aerial) reconnaissance flights in 1959. The flights crossed large areas of Victoria Island and were flown at altitudes from 30-300 m above ground level. The geologists only recorded 76 muskoxen in six herds, as well as a single animal, and 10 caribou.

In 1976 and 1979, the Northwest Territories Wildlife Service responded to reports of increasing muskox sightings with aerial reconnaissances in the vicinity of Holman and Cambridge Bay (Spencer 1976; Boxer 1979, unpublished reports, Northwest Territories Wildlife Service). Those surveys revealed increasing numbers of muskoxen. The trend in the numbers could not be quantified properly, however, until estimates of numbers were obtained from systematic surveys.

The first systematic aerial survey of wildlife on Victoria Island was part of the environmental evaluation for the Polar Gas Pipeline. The pipeline was proposed to carry gas from the High Arctic across western Victoria Island to the mainland. Jakimchuk and

Carruthers (1980) estimated 12,160 ± 2,890 (Standard Error) muskoxen and 7,936 ± 1,839 caribou in August 1980.

The Department of Renewable Resources resurveyed most of the areas in March and August 1983 (Jingfors 1984, 1985) and in March 1988 (A. Gunn, unpublished data). The results are not comparable to Jakimchuk and Carruther's (1980) results which were from a survey of summer distribution. Those authors covered only a small percentage of their survey area (about 6%) compared to the 20% in 1983 and 30% in 1988, which further reduces the comparability of the surveys.

Jingfors (1985) concluded from his estimate of 6,430 ± 498 muskoxen on northwestern Victoria Island, that the muskox population was stable. The proportions of calves, yearlings and two-year olds in the population in 1986, however, supported the hunters' contention that the population is increasing (A. Gunn, unpublished data). The 1983 and 1988 surveys and hunters' reports attest to a rapid recolonization of muskoxen on southwest Victoria Island, where Jingfors (1984) estimated 3,300 ± 345 in March 1983 and I estimated 11,988 ± 2,078 muskoxen in March 1988.

We have more information on muskoxen than caribou partly because of the greater ease of surveying muskoxen, but also because of the quotas. Muskoxen can only be hunted under a quota system, and requested changes to quotas are evaluated by surveys. Inuit subsistence hunting of caribou is not regulated by quotas, and without the need to evaluate quotas there was less impetus for caribou surveys. The difficulties of precisely estimating numbers of the inconspicuous caribou scattered over inconveniently large areas also hindered such surveys. The first step in improving the design of surveys for caribou was to describe seasonal distributions, especially during calving and rutting. Caribou gather for the rut and cows for calving, which facilitates counting and survey design at these times.

Caribou populations are conventionally defined on the basis of their annual return to traditional calving grounds (Thomas 1969; Gunn and Miller 1986). Definition of populations is an essential step in relating harvesting to the trends in population size, and historical information was insufficient to determine the discreteness of separate populations. The seasonal movements of 10 adult cows fitted with satellite-tracked transmitters in March 1987 were monitored (A. Gunn, unpublished data) to locate calving and rutting areas. Four cows moved toward Prince Albert Sound for calving and postcalving and then returned to the south coast of Victoria Island for the winter. Two cows spent the year on Wollaston

Peninsula; an area that was devoid of caribou in the 1930s (Freeman 1976) but used by caribou before the 1920s (Manning 1960). Two caribou cows calved and rutted north of Minto Inlet suggesting that they belong to a different population from the caribou south of Minto Inlet (Figures 2, 3).

Manning (1960) described the Dolphin and Union herd as distinct from, but more related to, mainland caribou than Banks Island Peary caribou. He suggested that the remnants of the Dolphin and Union herd were either absorbed into the mainland caribou or the resident Victoria Island caribou. This raises the question as to the subspecific as well as the population status of the caribou currently on Victoria Island. I am investigating the taxonomy by examination of serum proteins to measure genetic heterogeneity (Roed 1985), and by measuring skulls. Preliminary adult cow skull measurements (A. Gunn, unpublished data) clearly separate the caribou wintering on southern Victoria Island from mainland barren-ground caribou and High Arctic Peary caribou. The greatest resemblance is to the caribou measured from Prince of Wales Island and Boothia Peninsula (Manning 1960; Thomas and Everson 1982).

Harvest Information

Harvest information was not consistently collected until the inception of the Kitikmeot Harvest Study in 1982. Usher (1965) estimated from hunters' reports that some 150-200 caribou were harvested by the about 135 people living in Holman during 1962-1963. The population of Holman has about doubled since then, and the annual caribou harvest has more than tripled (625 ± 00, 1982-1987).

DISCUSSION

Changes in numbers and distributions of caribou and muskoxen on Victoria Island fall into three phases. Coincident with the establishing of coastal trading posts, caribou numbers sharply declined. The Dolphin and Union herd and the caribou crossing Dease Strait (which may, or may not, have been part of the former herd) ceased their seasonal migrations to winter on the mainland. Little is known about the decline of the muskoxen, though it may have preceded that of the caribou. Possibly, the muskox decline on western

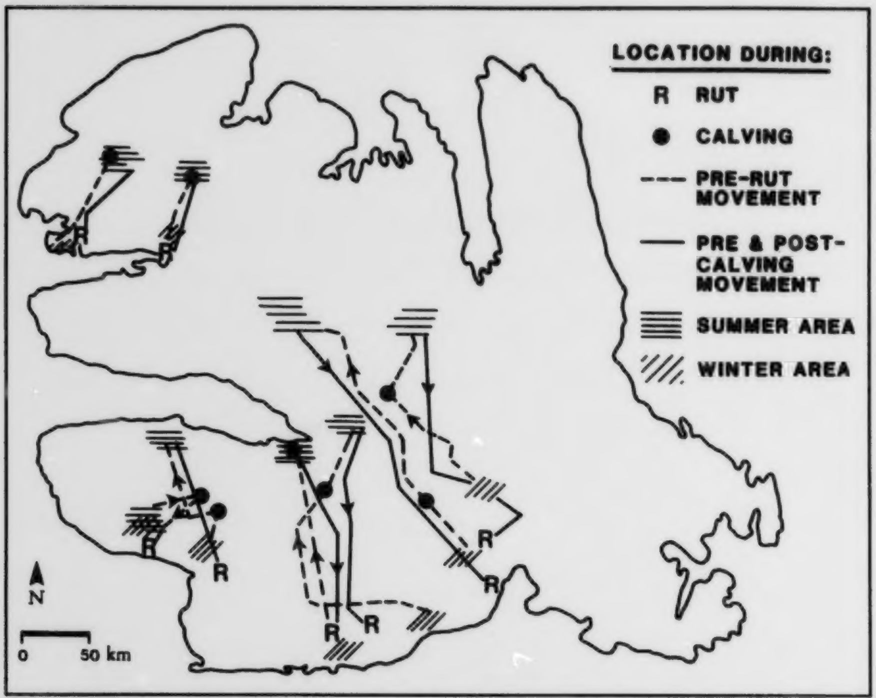

LOCATION DURING:
R RUT
● CALVING
--- PRE-RUT MOVEMENT
— PRE & POST-CALVING MOVEMENT
SUMMER AREA
WINTER AREA
R
N
0
50 km

FIGURE 2: Movement of adult cow caribou with satellite-tracked collars, Victoria Island.

FIGURE 3: Applying a satellite radiocollar to a female caribou.

Victoria Island coincided with the reduction of Banks Island muskoxen by the mid-1880s for unknown reasons. From 1920 to the early 1960s, caribou numbers farther north on Victoria Island continued to decline or stabilize at a low level, and the numbers of muskoxen also remained low or further declined (Freeman 1976). The third phase was one of increases in numbers of both species and a recolonization of southern Victoria Island.

Numbers of caribou and muskoxen have decreased and increased in the first half of this century on the mainland Northwest Territories. Those changes in population sizes are usually interpretated as the result of lifestyle changes among Inuit hunters that accrued from European influence. On Victoria and Banks islands, this explanation is not completely substantiated by the timing of the declines and the human cultural changes.

Clark (1986) described a "blip" in fur-seal (*Callorhinus ursinus*) bones found in kitchen-middens on Kodiak Island. The interpretation of the blip shows the need for precise dating before correlating changes in use patterns with conspicuous cultural changes. The use of fur seals only preceded European contact by perhaps a few decades. A less than precise analysis of the timing could lead to the conclusion that the introduction of the Asian and European influence triggered the utilization of the fur seals. More likely, an ecological change in the marine environment brought the seals within harvesting reach of the Kodiak natives (Clark 1986).

The timing of the reduction of the Dolphin and Union herd correlates with the establishing of trading-posts, and the effect of the firearms on the caribou is supported by eye-witness accounts (Manning 1960). Ascribing the subsequent declines in the more northern caribou and muskox populations to increased hunting pressure may be an oversimplification. The importance of finding whether ecological factors caused or compounded the decline in the caribou and muskox populations is of immediate management significance today.

Caribou and muskoxen (Figure 4) can double their populations every five to six years when conditions are good and mortality is minimal. Yet despite this potential, the populations have taken decades to recover. Once a population is reduced, however, even relatively low levels or mortality could hold it down.

Two considerations raise doubts about the prolonged decline in caribou and muskox populations being solely attributed to the effects of hunting. Firstly, the declines appeared relatively widespread over Victoria Island and possibly east on the mainland, though the extent that the reduction of each species is synchronized is uncertain.

Secondly, at the time of low ungulate populations from the 1930s to the late 1950s, human population had also decreased after exposure to European diseases (Usher 1965). Large northern and western inland areas of Victoria Island were not used for hunting or trapping (Freeman 1976). The nadir in the human population of Holman and Coppermine was in the early 1930s: not until the mid-1950s did the population return to the pre-contact level. Even in the early 1960s only 70-80 people lived along the northern and southern coasts of Dolphin and Union Strait, and about 135 people occupied the Holman area.

FIGURE 4: Muskox cow with a calf and a yearling, Victoria Island.

In the early 1950s, when the human populations began to recover, the prices of long furs had crashed. A comparison of the dispersion of traplines before and after 1955 suggests a contraction in areas covered and therefore hunted (Freeman 1976). The number of hunters with firearms to deplete widespread caribou and muskoxen seems low, although hunters travelled widely during the trapping season. After the loss of the large migratory herds, the caribou apparently did not concentrate seasonally in large numbers, which would have increased their vulnerability to overhunting (Freeman 1976). Finally, there were areas not apparently hunted which would have been refuges for caribou and muskoxen.

Hunters from Coppermine, Cambridge and Holman partly attribute the disappearance of caribou and muskoxen to exceptionally severe winters. Those discussions do not specify in which years the caribou died. Weather data shed no light on whether severe winters may have compounded the effect of hunting in depressing the populations in the 1920s and 1930s. Weather records in Holman cover the periods 1941-1969 and 1979 onward. In

Cambridge Bay, weather recording started in 1929, although there are many months without data until 1947.

On western Victoria Island there was, however, a series of severe winters with above average snowfall that persisted into June in the early 1960s and to a lesser extent in the 1940s. In Holman, winters with a total snowfall exceeding 100 cm occurred in 1943-44, 1947-48, 1958-59, 1959-60, 1960-61 (227.6 cm), 1961-62 and 1963-64. In Cambridge Bay, the range in annual snowfall is not so marked as on western Victoria Island, but snowfall exceeded 100 cm in the winters of 1940-41, 1963-64 and 1964-65. Those winters with above average snow depths in the 1940s and 1960s may have contributed to the slow recovery of the caribou and muskox populations.

Ocean-current temperature changes such as the West Greenland current (e.g. Vibe 1967; Dunbar and Thomsen 1979), and alterations in the upper atmospheric pressure systems (e.g. Barry *et al.* 1975) cause shifts in the trend of arctic temperatures and precipitation. Shorter-term changes such as one to two-year decreases in temperature and precipitation, and persistence of sea ice in the summer were caused by the dust-veil after the eruption of major volcanos in 1815, 1835, 1883, 1902, 1907, 1912 and 1963; in some cases compounded by anomalous atmospheric pressure conditions (e.g. Bradley and England 1978; Skinner 1985; Catchpole 1985, 1988). So far, most descriptions of shifts in climate have centred on the eastern Arctic (Greenland, Baffin Island, Hudson Bay and the High Arctic).

Efforts to correlate climate on Victoria Island with changes in the past numbers of caribou and muskoxen are tenuous. The relationships are barely known between the available meteorological measurements such as snow depth or snowfall and ungulate survival. There are relatively few instances where a winter die-off has been documented and the weather conditions known. Relationships are poorly known between snow depth and density; groundfast ice and ice lenses; their timing and duration and the forage availability for caribou (Miller *et al.* 1982) and muskoxen. Peary caribou and muskoxen died on the western Queen Elizabeth Islands during the winter of 1973-1974 (Parker *et al.* 1975); Miller *et al.* 1977). The winter of 1973-1974 started with a fall ice storm, followed by exceptionally deep snowfall that was late in melting. Caribou succumbed before muskoxen in late winter (Miller *et al.* 1977).

Caribou and muskoxen respond differently to severe winters. Conditions severe enough to kill caribou may not cause mortality of muskoxen. The 1972-1973 and 1976-1977 winters had snow deep enough to reduce forage availability for caribou to the point of fatal malnutrition on Banks Island, but not for muskoxen.

This comparative aspect of the ecology of caribou and muskoxen and the relationship of their strategies for winter survival are little understood. Yet, clearly there are such pronounced differences in feeding behaviour and comparative morphology that different winter survival strategies are inevitable. Differences in the peaks and valleys in annual fat cycles (e.g. Adamczewski 1987; Thing *et al.* 1987) and the timing of annual life-cycle phases, such as calving and the rut, further support the idea of dissimilar survival strategies.

Differences in the climate across Victoria Island are sufficient that Maxwell (1981) could divide the island into three climatic regions. The western is under Pacific maritime influence. Eastern Victoria Island has a more continental climate marked by greater annual extremes in temperature and lower precipitation. These climatic differences make attempts to relate the changes in numbers of caribou and muskoxen to climate more difficult.

Predation is a potentially important mortality factor in caribou and muskoxen ecology. Little is known about wolves (*Canis lupus bernardi*) on Victoria Island, but they were a subspecies rather closely related to the High Arctic wolf (*C.l.arctos*) (Nowak 1983). Banfield (1978) speculated that an immigration of the High Arctic wolf had swamped *C. l. bernardi.* Freeman (1976) refers to wolves as scarce but hunted near Minto Inlet from the 1930s onward. Five wolf pelts were sold between 1968 and 1980 from Holman, and seven pelts from 1981 to 1985. Sale records for the pelts underestimates the number of wolves harvested as the species was also killed because of its depredations along fox traplines in the 1960s and 1970s (personal communication, T.G. Smith).

In the 1980s, sightings of wolves are increasing, and Read Island and Holman trappers have complained about damage to trapped foxes by wolves (personal communications, D. Kuptana, J. Atatahak). In December 1986, four wolves were shot along a trapline on the southwestern coast of Victoria Island. Wolves now den at Wellington Bay (personal communication, D. Kaomayok) and packs of up to nine have been sighted at Wellington Bay and Minto Inlet (A. Gunn, field notes).

The sparse information is that wolves were not numerous on Victoria Island. Even low numbers of wolves can, however, exert significant pressure on a low prey population, but there is no evidence for or against this occurring in the 1930s to 1960s on Victoria Island.

Surprisingly, wolves are only slowly increasing despite the large prey base and the high potential rate of increase of wolves (Keith 1983).

The same pattern: decline of caribou and muskoxen in the 1920s and 1930s; low numbers until the 1960s; then recovery in the 1970s and 1980s, occurs elsewhere in the Canadian Arctic. Aerial surveys have documented the increase in caribou numbers near Boothia Peninsula, King William Island and the Back River Lowlands. The compilation of historical accounts and recollections of older hunters document an earlier decrease in numbers (Gunn and Lambert, in press; Gunn and Ashevak, in press). The decline and recovery of caribou numbers is also apparent among the large mainland herds of barren-ground caribou (Gates 1985; Heard *et al.* 1986) and on Baffin Island (personal communication, M. Ferguson).

The most complete evidence for cycling in caribou numbers comes from the documentation of four cycles of increase and decrease in a 250-year period in Greenland (Meldgaard 1986). However, the cycles are not completely periodic and there were regional differences in the synchronization of peaks and troughs. Meldgaard (1986) rejected hunting and predation in favour of climatic changes as driving the cycles.

Die-offs and reproductive failures as consequences of exceptionally severe winter weather are occasionally documented (e.g. Miller *et al.* 1977; Parker *et al.* 1975). The more subtle interactions between less dramatic trends in winter weather, survival and reproduction are little known. Thomas (1982), Adamczewski (1987) and others, however, have started to untangle the interactions between the effects of winter weather on forage availability, body condition and reproduction. Little is known about responses of caribou or muskoxen to the influences of summer weather on forage quality and phenology.

Subsistence use of caribou and muskoxen has been stable for Holman and Cambridge Bay in the 1980s despite the increase in numbers of caribou wintering close to the settlements. The annual replacement cost of the meat harvested is one million dollars - not accounting for the intangible values.

The dollar value of commercial use of caribou and muskoxen to the communities exceeds face value because of the importance of cash in the local economies. Most people are unemployed, which magnifies the importance of any source of cash. Local meat sales to hotels or community feasts, the sales of horns for carvings, and guided non-resident hunting were the only commercial uses of caribou and muskoxen. Commercial use of caribou and muskoxen expanded in 1987 with the opening of a small meat processing facility in Cambridge Bay. Central Arctic Meats Ltd. is affiliated with the Hunter's and Trapper's Association and hires hunters to harvest meat which is sold as jerky or frozen cuts.

People's cash expectations, and the justification of capital investments could provide momentum for commercial projects, even as the "resources" begin a downward swing in their population cycle. The Department of Renewable Resources gives priority to subsistence over commercial use, and would limit commercial use in the event of a population decline. Early warning of the state of the harvested population will be available from studies monitoring the health and physical condition of the caribou population. Population parameters (e.g. calf survival), and skeletal measurements (e.g. mandible or metatarsal length) respond to the availability of resources during different population phases (Meldgaard 1986; Couturier *et al.* 1987).

Our experience with population cycles of caribou and muskoxen is too short to determine whether the cycles are regular and periodic. Additionally, there are the uncertainties stemming from the prediction that anthropological factors may affect the climate. For example, the "greenhouse effect" from rising concentrations of carbon dioxide and other greenhouse gases in the atmosphere may cause increases in mean temperatures.

Monitoring of population-size trends is only one part of managing cyclic populations, as the rapidity of population changes may exceed the feasible frequency of monitoring population size. Phases of population increase and decrease only averaged 10 years in Greenland, though there were variations (Meldgaard 1986). The annual collection of skeletal measurements and other condition indices is an economical approach to monitoring the population phase. Other measures of body and reproductive condition are also easily taken and help track a population's response to prevailing climate.

Awareness of the response of caribou and muskoxen to climatic change (Harington 1986) has to be part of planning their utilization. The memories of the previous declines in caribou and muskoxen and government responses are a strong thread running through the current relationship between government and public (Clancy 1987). The potential of anthropological factors to alter climate hastens has the need to better understand the role of climate regulating, long-term changes in the numbers of caribou and muskoxen in the Northwest Territories.

ACKNOWLEDGEMENTS

This paper grew out of conversations with hunters from Cambridge Bay, Coppermine and Holman, and I especially thank David Kaomayok and Colin Adjun. I thank George Hobson and his staff (Polar Continental Shelf Project (PCSP)) for their support of arctic science. Involvement with PCSP has led to stimulating contacts and friendships which helped in writing this paper. In particular, Bea Alt (Geological Survey of Canada) helped me track down the snow data. C.R. Harington (National Museum of Natural Sciences) directed me to helpful references on climatic change. Janet Troje (J&T Graphics, Yellowknife) produced the illustrations, and Frank L. Miller (Canadian Wildlife Service) reviewed the manuscript.

REFERENCES

Adamczewski, J. 1987. Body composition in relation to seasonal forage quality in caribou (*Rangifer tarandus groenlandicus*) on Coats Island, Northwest Territories. M.Sc. thesis, University of Alberta, Edmonton. 139 pp.

Banfield, A.W.F. 1978. The mammals of Canada. University of Toronto Press, Toronto. 438 pp.

Barry, R.G., R.S. Bradley, and J.D. Jacobs. 1975. Synoptic climatological studies of the Baffin Bay area. In: Climate of the Arctic. Edited by: G. Weller and S.A. Bowling. 24th Alaska Science Conference, University of Alaska, Fairbanks. pp. 82-90.

Bradley, R.S. and J. England. 1978. Recent climatic fluctuations of the Canadian High Arctic and their significance for glaciology. Arctic and Alpine Research 10(4):715-731.

Catchpole, A.J.W. 1985. Evidence from Hudson Bay region of severe cold in the summer of 1816. In: Climatic Change in Canada 5. Edited by: C.R. Harington. Syllogeus 55:121-146.

______. 1988. Occurrence of severe ice in Hudson Strait and Hudson Bay following major volcanic eruptions, 1751 to 1889 A.D. Climatic Fluctuations and Man 3:67.

Clancy, P. 1987. Native hunters and the state: the 'caribou crisis' in the Northwest Territories. Studies in National and International Development, Queen's University, Kingston. SNID, Occasional Paper 87-101:1-32.

Clark, D.W. 1986. Archaeological and historical evidence for an 18th-century "blip" in the distribution of the northern fur seal at Kodiak Island, Alaska. Arctic 39:39-42.

Couturier, S., J. Brunelle, and G. LaPointe. 1987. Decline of physical condition and decrease of recruitment in the George River caribou herd. Paper presented at the Third North American Caribou Workshop (Chena Hot Springs, Alaska, 4-6 November, 1987).

Dunbar, M.J. and D.H. Thomsen. 1979. West Greenland salmon and climatic change. Meddelelser om Grønland 202(2):5-19.

Freeman, M.M.R. 1976. Inuit Land Use and Occupancy Project. Indian and Northern Affairs Canada, Ottawa. Volume I. 262 pp.

Gates, C.C. 1985. The fall and rise of the Kaminuriak caribou population. Proceedings of the Second North American Caribou Workshop. Edited by: T.G. Meredith and A.M. Martell. McGill Subarctic Research Paper No. 40:215-228.

Gunn, A. and F.L. Miller. 1986. Traditional behaviour and fidelity to caribou calving grounds by barren-ground caribou. Rangifer, Special Issue 1:151-158.

Gunn, A. and J. Ashevak. (in preparation). Abundance and distribution of caribou on Boothia Peninsula and west of Pelly Bay. Northwest Territories File Report.

Gunn, A. and K. Lambert. (in preparation). Abundance and distribution of caribou on King William Island and Adelaide Peninsula. Northwest Territories File Report.

Harington, C.R. 1986. The impact of changing climate on some vertebrates in the Canadian Arctic. In: Impact of Climatic Change on the Canadian Arctic. Edited by: H.M. French. Proceedings of a Canadian Climate Workshop, Atmospheric Environment Service, Downsview. pp. 100-113.

Heard, D.C., T.M. Williams, and K. Jingfors. 1986. Pre-calving distribution and abundance of barren-ground caribou on the northeastern mainland of the Northwest Territories. Arctic 39(1):24-28.

Jakimchuk, R.D. and D.R. Carruthers. 1980. Caribou and muskoxen on Victoria Island. Report prepared for Polar Gas Project by R.D. Jakimchuk Management Associates Ltd., Sidney. 93 pp.

Jingfors, K. 1984. Abundance and distribution of muskoxen on southeastern Victoria Island. Northwest Territories File Report 36:1-24.

______. 1985. Abundance and distribution of muskoxen on northwestern Victoria Island. Northwest Territories File Report 47:1-22.

Keith, L.B. 1983. Population dynamics of wolves. In: Wolves in Canada and Alaska. Edited by: L.N. Carbyn. Canadian Wildlife Service, Report Series 45:66-77.

Manning, T.H. 1960. The relationship of the Peary and barren-ground caribou. Arctic Institute North America, Technical Paper 4:1-52.

Maxwell, J.B. 1981. Climatic regions of the Canadian Arctic Islands. Arctic 34:225-240.

McGhee, R. 1976. An individual view of Canadian Eskimo prehistory. In: Inuit Land Use and Occupancy Project. Edited by: M.M.R. Freeman, Indian and Northern Affairs Canada. Ottawa. Volume II:109-116.

Meldgaard, M. 1986. The Greenland caribou - zoogeography, taxonomy, and population dynamics. Meddelelser om Grønland, Bioscience 20:1-88.

Miller, F.L., E.J. Edmonds, and A. Gunn. 1982. Foraging behaviour of Peary caribou in response to springtime snow and ice conditions. Canadian Wildlife Service, Occasional Paper 48:1-41.

Miller, F.L., R.H. Russell, and A. Gunn. 1977. Peary caribou and muskoxen on western Queen Elizabeth Islands, N.W.T. 1971-74. Canadian Wildlife Service, Report Series 40:1-55.

Nowak, R.M. 1983. A perspective on the taxonomy of wolves in North America. In: Wolves in Canada and Alaska. Edited by: L.N. Carbyn. Canadian Wildlife Service, Report Series 45:10-19.

Parker, G.R., D.C. Thomas, E. Broughton, and D.R. Gray. 1975. Crashes of muskox and Peary caribou populations in 1973-74 on the Parry Islands, Arctic Canada. Canadian Wildlife Service, Progress Notes 56:1-10.

Roed, K. 1985. Genetic variability in Norwegian semi-domestic reindeer (*Rangifer tarandus* L.). Hereditas 192:177-184.

Skinner, W.R. 1985. The effects of major volcanic eruptions on Canadian climate. In: Climatic Change in Canada 5. Edited by: C.R. Harington. Syllogeus 55:75-106.

Stefansson, V. 1923. My life with the Eskimos. MacMillan, New York. 538 pp.

Thing, H., D.R. Klein, K. Jingfors, and S. Holt. 1987. Ecology of muskoxen in Jameson Land, northeast Greenland. Holarctic Ecology 10:95-103.

Thomas, D.C. 1969. Population estimates and distribution of barren-ground caribou in Mackenzie District, N.W.T., Saskatchewan and Alberta - March to May 1967. Canadian Wildlife Service, Report Series 9:1-44.

______. 1982. The relationship between fertility and fat reserves of Peary caribou. Canadian Journal of Zoology 60(4):597-602.

Thomas, D.C. and P. Everson. 1982. Geographic variation in caribou on the Canadian Arctic Islands. Canadian Journal of Zoology 60:2442-2454.

Usher. P.D. 1965. Economic basis and resource use of the Coppermine-Holman region, N.W.T. Northern Co-ordination and Research Centre, Department of Northern Affairs and National Resources, Ottawa. 290 pp.

Vibe, C. 1967. Arctic animals in relation to climatic fluctuations. Meddelelser om Grønland 170:1-227.

Illustrated by Brenda Carter

INTER-ISLAND MOVEMENTS OF PEARY CARIBOU: A REVIEW AND APPRAISEMENT OF THEIR ECOLOGICAL IMPORTANCE

Frank L. Miller[1]

Abstract: Evidence is reviewed regarding the presence and persistence of seasonal inter-island migrations and sporadic inter-island movements at all times of the year by caribou (Rangifer tarandus sp.) in the Canadian Arctic. Inter-island migrations and movements by Peary caribou (R. t. pearyi) and their intergrades (R. t. pearyi x R. t. groenlandicus or R. t. groenlandicus x R. t. pearyi) in the Canadian Arctic Islands and the coastal mainland of Arctic Canada are emphasized. Early evidence indicates that mass migrations persisted between the mainland and the southern tier of islands; some smaller-scale migrations and sporadic movements between or among islands occurred or continued to occur within both the southern and the northern tiers of islands; but movements over the sea ice of Viscount Melville Sound, Barrow Strait, or Lancaster Sound were infrequent. Subsequent studies detailed inter-island populations of Peary caribou in the Melville-Eglinton-Prince Patrick islands region and Peary caribou, or their intergrades, in the Prince of Wales Island-Somerset Island-Boothia Peninsula region. These studies indicated that movements of caribou between the southern and northern tiers of islands remain infrequent. Evidently inter-island migrations and movements of caribou: (1) maximize seasonal use of the best ranges; (2) provide the greatest opportunities for relief from widespread environmental stresses; and thus (3) maximize the magnitudes and durations of population highs and minimize the lows. Inter-island movements are seen as "ecological manoeuvres" by Peary caribou and their intergrades to cope with and prosper in their harsh surroundings on the Canadian Arctic Islands.

Résumé: On passe en revue les éléments qui attestent de la présence et de la persistance de migrations saisonnières et de mouvements sporadiques du caribou (Rangifer tarandus) entre les îles de l'Arctique canadien en tout temps de l'année. L'accent est mis sur les migrations et les mouvements entre les îles du caribou de Peary (R. t. pearyi) et de ses croisements (R. t. pearyi x R. t. groenlandicus ou R. t. groenlandicus x R. t. pearyi) dans les îles de l'Arctique canadien et sur la côte du continent du Canada arctique. Les toutes premières indications montrent que les migrations de masse ont continué entre le continent et la partie sud des îles. Quelques migrations à plus petite échelle et des mouvements sporadiques à l'intérieur des îles ou entre elles ont eu lieu et se produisent encore dans les parties sud et nord des îles, par contre, les mouvements sur la glace de mer des détroits du Vicomte de Melville, de Barrow et de Lancaster ont été peu fréquents. Des études subséquentes ont porté sur les populations de caribous de Peary qu'il y avait entre les îles dans la région des îles Melville, Eglinton et Prince-Patrick de même que sur les caribous de Peary et leurs croisements dans la région des îles Prince-de-Galles et Somerset et de la péninsule de Boothia. Ces études ont démontré que les mouvements des caribous entre le sud et le nord des îles demeuraient peu fréquents. Bien entendu, les migrations entre les îles et les mouvements des caribous ont pour effet: (1) de faire un usage saisonnier optimal des meilleurs pâturages, (2) de fournir les plus grandes chances possibles de compenser le stress environnemental généralisé et donc (3) de favoriser l'ampleur et la durée des maximums de populations et d'en réduire les minimums. On considère les mouvements entre les îles des caribous de Peary et de leurs croisements comme des "manoeuvres écologiques" visant à affronter le dur environnement sur les îles de l'Arctique canadien et y prospérer.

INTRODUCTION

That caribou and reindeer (*Rangifer tarandus* spp.) are capable of extensive travel over sea ice is evident by their presence on most circumpolar arctic islands. The most impressive, and reasonably well documented account is for reindeer migrants on Spitsbergen having arrived there by travel over the sea ice from Nova Zemlya (Wollebaek 1926; Lønø 1959 in Banfield 1961; Banfield 1954, 1961). An individual reindeer shot on Spitsbergen had a gull's foot tied to one antler, which apparently was a ceremonial decoration put on reindeer by Samoyeds of Nova Zemlya during certain rituals. The most probable route

---

[1] Canadian Wildlife Service, 4999-98 Avenue East, Edmonton, Alberta T6B 2X3

from Nova Zemlya to Spitsbergen necessitates crossing at least 380 km of sea ice from Nova Zemlya to Franz Josef Land, then another 340 km to Spitsbergen. Otherwise the reindeer would have had to travel about 800 km without feeding. Hakala *et al.* (1985, p. 9) give the distance as, "Novaya Zemlya to Kong Karls Land via Franz Joseph Land is 380 + 340 km and a further 90 km to Edgeoya".

I restrict the term "migration" to those movements of caribou that are traditional, seasonal, and annual and which are most likely perpetuated by learned behaviour. The term "movement" applies to all displacements of caribou whether traditional migrations, or periodic or sporadic responses to social intolerance (most likely density-dependent), or widespread forage unavailability (environmentally forced and can be either density-dependent or density-independent (Miller *et al.* 1982)). Also I have adjusted early taxonomic references to *Rangifer* to agree with Banfield's (1961) revision of the genus. That is, all caribou belong to the species *tarandus* and the subspecific forms considered for Canada are *R. t. pearyi*, *R. t. groenlandicus* and their intergrades (both *pearyi* x *groenlandicus* and *groenlandicus* x *pearyi*).

Now, let us review the evidence for consistent inter-island movements of Peary caribou, and subsequently speculate about how such movements make the continued survival and evolutionary divergence of *pearyi* and *pearyi* x *groenlandicus* possible.

CIRCUMSTANTIAL EVIDENCE FOR MIGRATIONS AND MOVEMENTS OF CARIBOU ACROSS SEA ICE

Evolutionary and Historical Background

Banfield (1961, p. 65) indicated that Peary caribou (*R. t. pearyi*) and the now-extinct East Greenland reindeer (*R. t. eogroenlandicus*) were closely related. More recently, Willemsen (1983) and Hakala *et al.* (1985) have remarked on the similarity among *pearyi*, *eogroenlandicus*, and the Svalbard reindeer (*R. t. platyrhynchus*), thus indicating a close taxonomic affinity among all three forms of arctic island caribou. Further support for this relationship has been put forth by Røed *et al.* (1986) with the finding that one of only two alleles that coded for transferrin in the Svalbard reindeer is held in common with *pearyi* (neither are found in continental reindeer or caribou). Thus, progenitors of Peary caribou were capable at some time, of making sea ice crossings, most likely, from the

Canadian Arctic Archipelago to at least northern and eastern Greenland and eventually to the Spitsbergen Archipelago.

By comparison, ancestral Peary caribou had only to make short sea ice crossings from coastal mainland areas to reach the southern tier of islands in the Canadian Arctic Archipelago. Those southern islands of Banks, Victoria, King William, Prince of Wales, and Somerset are only a few hours travel, on the sea ice, away from the north coasts of Boothia, Adelaide, and Kent peninsulas. However, crossing almost anywhere along Dolphin and Union, Rae and Franklin straits; or even Coronation and Queen Maud gulfs would require only several hours to a day's travel on the sea ice without feeding. (I have observed caribou coming off the ice of Peel Sound after travelling about 50 km from Somerset Island to Prince of Wales Island, and they showed no outward signs of hunger, working slowly inland and feeding casually as they moved.)

The second basic step in occupying most of the Arctic Islands (there is no evidence for Peary caribou ever having established themselves on Baffin or Bylot islands) required more extensive travel on sea ice in the west across Viscount Melville Sound from Banks or Victoria islands to Prince Patrick or Melville islands, and in the east across Lancaster Sound from Somerset Island to Devon Island. However, relatively short island-hopping treks across the Barrow Strait ice were possible from Prince of Wales Island to Bathurst or Cornwallis islands. For example, caribou could travel from the north shore of Prince of Wales to Russell, then via Russell-Hamilton-Young-Lowther-Garrett-Moore islands onto the south shore of Bathurst Island. Such a trip would involve a maximum of about 30 km of sea ice travel without landing for feeding in the 190 km (overall minimum) trek from Prince of Wales Island to Bathurst Island.

Most likely during the last (Wisconsin) glaciation, Peary caribou found refuge in the Canadian Arctic Archipelago - probably on Banks and Prince Patrick islands (Harington 1970, 1978), and possibly on northern Ellesmere Island and northern Greenland (e.g., Rand 1954; Banfield 1961, 1963; Macpherson 1965; Harington 1971; Hakala *et al.* 1985). However, Degerbøl (1957) and more recently Meldgaard (1986) have argued against northern Greenland or the Canadian Arctic Islands having served as refugia for Peary caribou during the Wisconsin glaciation.

Following the last glaciation, precursors of the current Peary caribou radiated out from wherever their refugium or refugia existed to colonize or recolonize the Canadian Arctic

Archipelago (except Baffin and Bylot islands). At least during the last phase of caribou dispersal in the Canadian Arctic Islands, the southern tier of islands was occupied to varying degrees by both *pearyi* and *groenlandicus* forms, and eventually by intergrades of both forms (*pearyi* x *groenlandicus*). Some intergrades favour the characteristics of *pearyi* (e.g., the Banks Island caribou) and some favour the characteristics of *groenlandicus* (e.g., caribou of the Dolphin and Union herd).

The annual seasonal migrations of the Dolphin and Union herd from winter ranges on the mainland to calving areas and summer ranges on Victoria Island (and possibly Banks Island), and return in the autumn (Manning 1960) attests to the relative ease by which such sea ice crossings are made by caribou. Other groups of caribou (apparently both *pearyi* x *groenlandicus* and *groenlandicus* forms) also made, or are still making, regular annual seasonal migrations or only sporadic crossings from Adelaide, Boothia, and Kent peninsulas to island calving areas and summer ranges on eastern Victoria, King William, Somerset, and Prince of Wales islands (Manning 1960; Banfield 1961; Manning and Macpherson 1961; Miller and Gunn 1978, 1980; Miller and Kiliaan 1980A, 1981; Miller *et al.* 1982; Thomas and Everson 1982; personal communication, A. Gunn). There is no evidence to suggest that caribou ever migrated across Viscount Melville Sound, Barrow Strait, and Lancaster Sound between northern and southern islands of the archipelago. However, human habitation ceased in the area several hundred years before the coming of European explorers in the 1800s and was only reestablished in the 1950s (Bissett 1968). Therefore, the likelihood of routine seasonal migrations on an annual basis before the 1950s is unknown. There is indirect evidence from cast caribou antlers and caribou fecal droppings, along with rapidly changing numbers of caribou on several of the small islands of Barrow Strait, that caribou have made at least sporadic treks over sea ice to those islands (Bissett 1968; Freeman 1974; Miller and Gunn 1978, 1980). However, the origins, final destinations, and directions of travel are usually undetermined.

There is no evidence that *groenlandicus* individuals were ever successful at establishing themselves on the Queen Elizabeth Islands (QEI). However, *groenlandicus* caribou established themselves on Baffin and Bylot islands, whereas *pearyi* caribou have not (possibly deeper snow cover on Baffin Island, compared to islands in the western archipelago, favours the survival of the relatively long-legged barren-ground form over the short-legged Peary caribou of the High Arctic).

Probably the answer lies mainly in the relative abundance and higher quality of summer ranges on the large southern islands, especially Banks and Victoria, compared to those on the QEI. The ability of summer ranges on the southern islands to support high densities of caribou is evident by the prolonged history of wintering mainland caribou calving and summering there. Additional benefits afforded those caribou likely were relative freedom from biting and blood-sucking insects, wolves (*Canis lupus*), and brown bears (*Ursus arctos*) compared to possible adjacent mainland summering ranges.

Frequent waves of barren-ground caribou migrated over the sea ice, pushing northward to the southern tier of islands. They usually remained only seasonally, but in the long run intergraded with resident Peary caribou and became the dominant southern island form (*pearyi* x *groenlandicus*). For unknown reasons barren-ground caribou only have been successful in colonizing the extreme eastern portion of the Arctic Islands (Baffin and Bylot) on a year-round basis. Whether Peary caribou have attempted to colonize those areas or have been excluded by the barren-ground form is unknown. Elsewhere on the southern islands the barren-ground form is known only to be successful as a summer migrant. Year-round occupation seemingly favoured the merging of *pearyi* and *groenlandicus* features, thus apparently creating a better adapted intergrade. I am not aware of evidence suggesting that caribou on Victoria Island are possibly "environmentally modified" *R. t. groenlandicus*. The original Peary caribou that occurred on the southern islands had their gene pool contaminated to varying degrees by the barren-ground form. Seemingly, this contamination has been unfavourable in terms of survival on the High Arctic islands, as no intergrades (or barren-ground caribou) are known to have established themselves on the QEI. So Peary caribou on the QEI remain essentially pure, and exhibit typical characteristics of the *pearyi* form (Banfield 1961; Thomas and Everson 1982).

Thus, the stage is set for the further evolution of *pearyi* on the QEI through physiological and behavioural adaptations to their more demanding surroundings. It is obvious from the foregoing that the ability of caribou to periodically or sporadically travel extensively over sea ice has made widespread occupation of the Canadian Arctic Archipelago possible.

Migration and Movements between the Mainland and Southern Islands

Habitation by indigenous peoples shortly before and after contact with Europeans was restricted largely to coastal mainland areas and the southerly portions of the southern islands in the archipelago, until Resolute Bay and Grise Fiord were settled in the High Arctic in the 1950s. Also, sea ice crossings by caribou between the mainland and the southern islands were massive and used by more people; so probably because they were obvious and important, they were more often reported. Most direct observations and circumstantial evidence in the literature support persistent periodic seasonal migrations or sporadic movements of caribou throughout the year on the sea ice between the mainland and the southern islands. The best documented early evidence is for the Dolphin and Union herd (Manning 1960; Gunn, this volume).

First reports of extensive caribou migrations over sea ice between Victoria Island and the mainland were made by Franklin (1823, p. 395), Sabine in Franklin (1823, p. 665), and Simpson (1843, pp. 277-278). However, Rae (1852, p. 79) was apparently the first to actually observe caribou crossing the sea ice of Dolphin and Union Strait in spring 1851. Collinson (1889, pp. 244, 290) offered the first evidence for fall migration of caribou from eastern Victoria Island south across the frozen waters of Dease Strait to Kent Peninsula in 1853. Over 50 years passed before additional information was obtained on such migrations (Manning 1960, p. 7).

In the early 1900s, there were a number of brief accounts on migrations and movements of caribou - primarily between the mainland and Victoria Island, but also King William Island, and to a lesser extent Banks Island. Those records include information on migrations and movements of caribou from and to the mainland across the sea ice of Dolphin and Union Strait, Coronation Gulf, Dease Strait, and to a lesser extent Queen Maud Gulf. More specifically the records included data on: (1) the northward spring migrations and southward fall migrations; (2) numbers of caribou involved, including group-sizes; and (3) the dying out of the major migrations (Anderson 1913A, p. 6, 1913B, pp. 502-503, 1920, p. 544, 1922, pp. 73-74; Stefansson 1913A, pp. 94-95, 99, 106, 1913B, pp. 203-204, 277, 1914, pp. 41, 54, 1920, pp. 135-136, 1921, pp. 401-402; Chipman 1920, p. 101; Jenness 1920, pp. 167-168, 1922, pp. 15, 244, 1928, pp. 12-13, 187-190; Johansen 1920, pp. 136-137; Hoare 1920, pp. 76, 80, 1925, p. 1-3, 7, 10-11, 1927, pp. 33, 36; O'Neill 1920,

p. 37; Storkerson 1920, pp. 277; Rasmussen 1927, p. 246; Godsell 1937, pp. 288-289, 1943, pp. 273-274; and Clarke 1940, p. 98).

Inuit mentioned large numbers of caribou passing by Sachs Harbour in November 1951 and travelling onto the sea ice south of Banks Island. Apparently some returned to Banks Island later in the winter and died there (or others that stayed on the island died). A Holman Island Inuk reported that some Banks Island caribou crossed to Victoria Island and to the mainland near Herschel Island then. McEwen (1955, pp. 45-46) reported a large number of caribou on the sea ice off southwestern Banks Island in October 1952. In addition, he obtained reports from local Inuit of Banks Island caribou in November and December 1952 at Holman Island, Cape Parry, Baillie Islands, Cape Dalhousie, and possibly Herschel Island. Youngman (1975, p. 167) records *R. t. pearyi* (most likely from Banks Island) as an occasional migrant in the Yukon Territory, occurring at least as far south as Old Crow. An adult female was killed during winter 1963-1964 near Old Crow, which most closely resembled a Dolphin and Union herd intergrade.

M'Clintock (1859, pp. 250, 252) mentions migration of caribou from the mainland to King William Island. Macpherson and Manning (1959, pp. 55-56) summarize circumstantial evidence and observations by others on caribou crossing sea ice between the mainland and King William Island. There appeared to be at least two main routes across Simpson Strait: one from Eta Island (Gilder 1881, pp. 196-197; Amundsen 1908, Volume 1, p. 104; Rasmussen 1927, p. 214); and one past Todds Island (Amundsen 1908, Volume 1, pp. 97-105, 247). Herds apparently staged in the Gjoa Haven area from September to October (Gilder 1881, pp. 196-197; Amundsen 1908, Volume 1, pp. 84-99, 104, 106, 247-248). Migrations of barren-ground caribou from winter ranges on the mainland to calving areas and summer ranges on King William Island were drastically reduced by the 1920s (Hoare 1927, p. 37) and apparently ceased about the late 1920s and early 1930s (Burwash 1931, p. 66; Gibson 1932, p. 405).

Migration and Movements among the Southern Islands (Including Boothia Peninsula)

Manning and Macpherson (1958, pp. 65-67) summarize evidence for movements between Banks and Victoria islands. Armstrong (1857, pp. 297, 336) recorded three caribou crossing via the Princess Royal Islands on 6 January 1851 - apparently coming from Banks Island. M'Clure (1856, p. 156) also reported a crew member seeing "a small herd" of caribou trotting toward the Princess Royal Islands. Collinson (1889, p. 200) saw several caribou trails coming from Banks Island on the sea ice near Peel Point, Victoria Island on 31 May 1852.

M'Clintock (1859, p. 186) saw caribou apparently waiting for the freeze-up of Bellot Strait to continue their southward migration from Somerset Island to Boothia Peninsula.

Manning and Macpherson (1961, pp. 219, 221, 222, 226-227) summarize circumstantial evidence and a few direct observations. Inuit of Resolute Bay knew of spring sea ice crossings by caribou from Somerset to Prince of Wales islands in the 1950s. Hearsay evidence was also offered for regular migrations and crossings of mainland caribou from Boothia Peninsula to Somerset Island: northward in spring before break-up and southward again before, during, and after freeze-up. They also reported that caribou (presumed to be Peary caribou) were seen on Boothia Peninsula: one was killed on Matty Island between Boothia Peninsula and King William Island. Fresh caribou tracks were reportedly seen on the ice of Bellot Strait between Somerset Island and Boothia Peninsula in mid-October.

Knowledge of inter-island migrations and movements among Somerset Island, Prince of Wales Island and Boothia Peninsula, as well as observations of caribou tracks on the sea ice in spring and autumn (reported by others) were also mentioned by Macpherson (1959), Bissett (1968), Fischer and Duncan (1976), Miller and Gunn (1978, 1980), Thompson and Fischer (1980), and Gunn and Miller (1983).

Manning and Macpherson (1961, p. 227) presumed little gene flow among caribou between Victoria Island and Prince of Wales Island via ice on M'Clintock Channel. However, Cambridge Bay Inuit who had lived or travelled in the area believe that caribou cross the sea ice of M'Clintock Channel between Victoria and Prince of Wales islands via Gateshead Island (personal communication, A. Gunn).

Queen Elizabeth Islands

The lack of early circumstantial evidence for inter-island movements of Peary caribou for the QEI stems from a near absence of observers. Inuit knowledge only extends from the 1950s until present (e.g. Bissett 1968; Freeman 1975; Miller and Gunn 1978, 1980). Indirect evidence for inter-island movements comes from changing numbers of caribou seen during aerial surveys from the late 1950s to the 1980s (e.g. Macpherson 1961; Tener 1963; Miller *et al.* 1977A).

Parry (1821, pp. 107, 110, 173) mistook autumn intra-island caribou movements to coastal areas for migration from eastern Melville Island to the mainland in autumn and their return in spring.

M'Dougall (1857, p. 398) saw five caribou on 25 May 1854 crossing McDougall Sound from Bathurst Island to Cornwallis Island.

McMillan in Bernier (1910, p. 475) reported that caribou tracks were frequently seen on the sea ice, and herds were seen crossing from "... one island to another" (possibly among Melville, Byam Martin, and Bathurst islands).

Stefansson (1921, p. 554) observed caribou tracks 5 km south of Jenness Island (off the west coast of Borden Island) in September 1915.

A.H. Joy of the Royal Canadian Mounted Police, based on extensive sled journeys in the QEI in the late 1920s, made detailed remarks on the numbers and migration of Peary caribou among some of those islands (Harington 1982, p. 558).

Tener (1963, p. 28) saw caribou tracks leading out onto the sea ice from Mackenzie King to Borden Island in 1961, and suggested that the high density of caribou on Borden Island could have been caused in part by "occasional or seasonal immigration". Macpherson (1961, pp. 12) also suggested that inter-island movements were the cause of varying caribou numbers on Brock, Borden and Mackenzie King islands.

Riewe (1978, pp. 635-636) reported that Inuit knew of caribou movements over the sea ice from the south coast of Ellesmere Island to Smith and Cone islands and then to the area around Starnes or Fram fiords.

Manning (1960, p. 43), when reviewing the relationship between Peary and barren-ground caribou, stated that because of the short distances involved in making sea ice crossings among the QEI, no serious barriers to free movements existed. He concluded that the QEI population should be homogeneous, and that it was homogeneous based on specimens available then. Banfield (1961, p. 63), in his revision of the genus *Rangifer*, stated, without giving sources, that free interchange among the QEI by inter-island crossings on the sea ice had been observed in a "few cases and clearly indicated in many others".

I conclude from this early evidence, that migrations across the sea ice of tens of thousands of caribou (possibly 100,000-200,000 at peaks) occurred in the spring (March-June) from mainland winter ranges to calving areas and summer ranges on Victoria, King William, and possibly Banks islands, returning each fall (end of October to December) to the mainland. Apparently those migrations continued uninterrupted from at least the early 1800s to the early 1900s, a minimum of about 75 years. Also, there were large migrations of caribou between northern Boothia Peninsula, Somerset and Prince of Wales islands - northward in spring and southward in fall. Then, apparently as a result of drastically increased kills made possible by the introduction of firearms, those migrations essentially ceased. However, recently Gunn (this volume) has argued that changing climate could have played a role in the drastic caribou reductions in the region, and thus in the cessation of large-scale migrations. Nevertheless, I think that the migratory caribou could not have sustained the levels of killing that took place in the early 1900s, regardless of environmental pressures then. Perhaps both factors worked together to decimate these caribou.

Early evidence does not indicate large seasonal migrations between Banks and Victoria islands, but it does indicate sporadic movements across Prince of Wales Strait throughout the winter. Although no early direct evidence exists to support seasonal caribou migrations between Somerset and Prince of Wales islands, Inuit knowledge after the 1950s argues for such migrations. The evidence does not suggest regular migrations across Viscount Melville Sound, Barrow Strait, or Lancaster Sound. Caribou sporadically crossed to the small islands of Barrow Strait, if not completely across the strait or sounds. Apparently travel was both north and south. It could be argued that movements between the southern islands and the QEI occurred at low frequencies and numbers based on indirect information. Evidence for inter-island movements among the QEI before the 1970s is based on a few early observations. Large seasonal caribou migrations among the QEI were suggested (1950s to 1970s) by both the taxonomic homogeneity of the specimens from the QEI and the observed changes in seasonal and annual numbers and distributions of caribou seen on various islands during aerial surveys.

INVESTIGATIONS OF INTER-ISLAND MIGRATIONS OR MOVEMENTS

Circumstantial evidence and incidental observations accumulated for over 150 years before the first actual investigation of inter-island movements of caribou in the Canadian Arctic Archipelago was initiated. While carrying out aerial surveys of the western QEI in 1972 and 1973, Miller *et al.* (1977A) noted that differences in numbers and distributions of caribou between March-April and July-August suggested that seasonal migrations were occurring among Melville, Eglinton, and Prince Patrick islands.

By aerial dye-spraying, Miller *et al.* (1977B) marked nearly 230 caribou in April 1974 (about 130 green-marked on Prince Patrick Island, and about 100 red-marked on Eglinton Island). Aerial searches flown in fixed-wing aircraft between 8 June and 23 July resulted in 41 sightings of dye-marked caribou (Miller *et al.* 1977B). Subsequently red-marked caribou were seen on Melville and Prince Patrick islands, as well as being relocated on Eglinton Island, while green-marked caribou were located on Melville and Eglinton islands as well as being relocated on Prince Patrick Island. Unmarked caribou were observed travelling on the sea ice in May and June. Caribou trails led to and from the northern two-thirds of the west coast of Eglinton Island and the opposing section of the east coast of Prince Patrick Island. Other trails led directly from the east coast of Prince Patrick Island, north of Eglinton Island and directly to Marie Heights and Canrobert Hills on western Melville Island. Still other trails led from northeastern Eglinton Island to western Melville Island (Canrobert Hills and the area south of Ibbett Bay). A few trails left the southern coast of Eglinton Island, apparently reaching Comfort Cove and Cape Russell areas of southwestern Melville Island. (It should be noted that because caribou usually walk in single file - often stepping in each others tracks while migrating - estimating the number of caribou that lay a trail is at best very difficult. If only a few caribou (perhaps 5-10) are involved the number can usually be discerned. However, if about 25 or more used the same trail, the number of caribou cannot be judged accurately in the absence of direct observation).

The longest movement detected involved a green-marked caribou that likely travelled at least 600 km between Prince Patrick Island (where it was marked) and eastern Melville Island (where it was last seen).

Miller *et al.* (1977B) estimated that 50% and 87% of the caribou that had wintered on Prince Patrick and Eglinton islands, respectively, had made inter-island movements sometime in spring and/or early summer. Their findings led them to believe that an inter-island migratory population of Peary caribou existed at least within the Melville, Prince Patrick, Eglinton islands region. These and other results (Miller *et al.* 1977A) in 1972-1974 led them to speculate that during periods of high densities those Peary caribou likely expanded the number of islands used as seasonal range to include Emerald, Byam Martin;

probably Mackenzie King, Borden, and Brock; and at extreme highs might occasionally extend farther northeastward and eastward encompassing most of the QEI (except perhaps for Devon, Axel Heiberg and Ellesmere islands).

Three years passed before the opportunity arose again to investigate inter-island caribou movements. This time the studies took place over four springs from 1977-1980 (Miller and Gunn 1978, 1980; Miller and Kiliaan 1980A, 1981).

In 1977 the investigation of inter-island Peary caribou movements was supplementary to another study (Miller and Gunn 1978, 1979; Gunn and Miller 1980). Search areas included the frozen waters of Peel Sound, Viscount Melville Sound, Barrow Strait and Baring Channel. Low-level (10-25 m above the sea ice) searches in a Bell-206B helicopter were flown over the ice and adjacent coastal areas between 12 and 18 June. Hamilton, Young, and Russell islands were surveyed by helicopter between 15 and 25 August. The search revealed 158 caribou trails on the sea ice and 31 additional trails on land adjacent to sea ice crossings. This confirmed large-scale inter-island movements of caribou in June 1977. The 95 trails across Peel Sound and the 63 trails across Baring Channel involved at least several hundred caribou. Apparently movements were entirely east-west from Somerset Island to Prince of Wales Island; then, south-north for those individuals crossing from Prince of Wales to Mecham and/or Russell islands. Many caribou from Somerset Island moved along the eastern satellite islands of Prescott, Vivian, and Lock to Prince of Wales Island. Evidence for sea ice crossings on Viscount Melville Sound and Barrow Strait were meagre. Trails leading onto the ice from Russell Island toward Young, Lowther, and Bathurst islands were soon obliterated due to obscuring snowcover and could not be followed. In August 1977 aerial searches revealed no caribou on Hamilton Island (but winter fecal pellets were seen), 22 caribou on Young Island, and 20 on Lowther Island. Those caribou had not been seen in May 1977 during similar searches.

The first year's (1977) effort indicated that caribou were indeed making large-scale inter-island movements, most likely from winter ranges on Somerset Island to calving areas and summer-ranges on Prince of Wales and Russell islands (and to a much lesser degree on small islands such as Young and Lowther). Based on that information, a more intensive search was planned for spring 1978.

Low-level searches were flown in a Twin Otter aircraft and a Bell-206B helicopter between 16 May and 1 July 1978 by Miller and Gunn (1980). They found 422 trails on the sea ice, distinguished tracks of at least 1,033 individuals, and saw 53 caribou making inter-island crossings on the sea ice. Most (91.7%) of the trails were associated with sea ice crossings among Somerset Island, Boothia Peninsula, and Prince of Wales Island (including Prince of Wales' eastern satellite islands of Lock, Pandora, Prescott and Vivian). Thirty-two (7.6%) of the trails crossed Baring Channel between Prince of Wales and Mecham or Russell islands. Only three (0.7%) trails were found leaving the north shore of Russell for Barrow Strait but, as in 1977, they were obliterated after several kilometres. No trails were found on the frozen waters of Viscount Melville Sound or Intrepid Passage. Approximately 3.1% of the trails were made between 16 and 31 May; 9.5% between 3 and 14 June; and 87.4% between 17 June and 1 July.

Again in 1979, investigation of spring inter-island movements was carried out supplementary to another study (Miller and Kiliaan 1980A,B). The frozen waters of Peel Sound, Franklin Strait, Baring Channel and Bellot Strait were searched by snowmobile and Bell-206B helicopter at irregular intervals from 5 May to 1 July 1979. Miller and Kiliaan found 103 trails on the sea ice, noted the tracks of at least 300 individuals, and saw 25 caribou making sea ice crossings. Most (73.8%) of the trails were seen on Peel Sound, followed by 19.4% on Franklin Strait, and only 3.9% and 2.9% on Bellot Strait and Baring Channel, respectively. Inter-island caribou movements varied somewhat in the spring of 1979 from those observed in the springs of 1977 and 1978. Nearly half (46.7%) of the observed trails were made in May, and for the first time spring caribou crossings from west to east were detected on both Peel Sound and Franklin Strait. However, whether the caribou that travelled eastward from Prince of Wales Island to Somerset Island or Boothia Peninsula summered there or subsequently returned to Prince of Wales to summer is unknown.

Snowcover remained thin on eastern Prince of Wales Island throughout the winter of 1978-1979 until April-May when it increased markedly. Observations in March 1977, 1978 and 1979 on eastern Prince of Wales Island suggested that there were many more caribou there in 1979 than in 1977 or 1978 (personal communication, D.C. Thomas). Perhaps more caribou than usual remained on Prince of Wales during the winter of 1978-1979 because of the lack of significant snowcover until April-May. Then in May, many caribou responded to the increased snowcover by migrating to Somerset Island or Boothia Peninsula. Probably many of them subsequently returned to their traditional spring calving areas and summer ranges on Prince of Wales in late June or early July 1979.

The fourth and final year of investigation was carried out in association with another study in 1980 (Miller and Kiliaan 1981; Miller *et al.* 1982). Low-level searches in a Bell-206B helicopter were flown over the ice of Peel Sound and Franklin Strait between 14 and 22 June 1980. Miller and Kiliaan found 588 caribou trails on the sea ice, recorded tracks of at least 1,799 individuals, and saw 15 caribou making sea ice crossings. Most (96%) of the 406 trails seen on Peel Sound were from east to west, as were all 31 trails seen on Franklin Strait.

This four-year investigation demonstrated the existence of an "inter-island population" of caribou within the Somerset Island-Boothia Peninsula-Prince of Wales Island region. The usual pattern appears to be calving and major use of summer ranges on Prince of Wales Island, an assumed early winter return to winter ranges on Somerset Island and/or Boothia Peninsula. Incidental observations have been made of caribou crossing Peel Sound from west to east on new ice in late October (Miller and Gunn 1980). No attempts have been made to document early winter migrations of caribou because of the unfavourable and unpredictable flying weather then. Also, findings from 1979 suggest that many caribou may remain on summer ranges well into the winter before increasing snow depths trigger their return to traditional winter-areas. In such years the return to winter ranges may be in successive waves or staggered movements rather than a discrete migration.

THE IMPORTANCE OF INTER-ISLAND MOVEMENTS TO PEARY CARIBOU

Caribou have two or three types of inter-island movements on the Canadian Arctic Islands. The first is annual seasonal migration, the second is sporadic environmentally-forced movement, and the third may arise occasionally by chance or due to a seemingly innate "restlessness" of the species.

Annual seasonal migrations usually involve many caribou making inter-island movements from traditional winter ranges in the spring to traditional calving areas and summer ranges, returning in fall to winter areas. Perhaps these periodic migrations or the sporadic inter-island movements (especially the environmentally-forced ones) foster continual gene-flow among QEI caribou and also among intergrades on the southern tier of islands. The apparent lack of constant interchange should, however, ensure continued divergence between *pearyi* on the QEI and intergrades (*pearyi* x *groenlandicus*) on the southern islands.

Theoretically, Peary caribou (and its intergrades) could maximize their chances of survival over time by exploiting as many feasible alternatives as possible. Thus, I would expect to find caribou throughout the archipelago exhibiting different survival strategies: some being truly migratory on an annual seasonal basis; others being essentially sedentary but occasionally undertaking inter-island migrations or movements in periods of severe environmental stress; while still others remained sedentary. What is "good" for a species or race in the long-term is not necessarily always "good" for all individuals involved in those activities in all years. For example, in June 1974 snow and ice conditions on Prince Patrick and Eglinton islands were relatively much more favourable for caribou than on eastern Melville Island in June-July 1974. However, parturient female caribou left Prince Patrick and Eglinton islands, crossed to Melville Island, travelled over its rugged western terrain, and fought deep snow and generally hard travelling conditions to reach their traditional calving and summering areas on eastern Melville Island. Apparently, many of the cows either did not calve or they were so delayed that they calved en route and lost their calves before even reaching eastern Melville Island. Others calved there, but most failed to rear their calves, probably because of the severe physical stress caused by their travels. The result was an almost total loss of the 1974 calf crop and the deaths of many mothers. Had the cows remained on Prince Patrick or Eglinton islands and calved there, they most likely would have been more successful in that particular year. Yet, they responded, with fatal results, to "traditions" that until then had favoured their survival and that of their forerunners over the long-term.

Seasonal alterations in range have several advantages. Abandonment of winter ranges reduces the annual use of those ranges and allows plants to recover from grazing during the summer growing period, thus maximizing available forage during the following winter. Also, the use of small islands for summer ranges maximizes the amount of available range during a period when small landmasses will support relatively high numbers of grazers. Those same islands can only support a small fraction of those animals during the winter, and year-round occupation at high densities could not be sustained. Also, probably seasonal shifts in range might, at least temporarily, provide relief from predation and reduce exposure to parasites and various diseases.

The extent and magnitude of annual seasonal migrations among islands is likely density-dependent, with both increasing innate social intolerances and stresses from limited forage serving as catalysts for such movements. Once established, inter-island movements will be perpetuated through "learned behaviour" as "traditional behaviour patterns" until changes in population size or the environment alter or end the traditional response. Evidence from Greenland supports the possibility that traditional migrations may sometimes originate from an environmentally-forced movement due to a chance event. Vibe (1967, pp. 176-177) states "... a sudden icing-up of the country was apparently the original cause of the migration. Ever since that time the Reindeer have wandered constantly towards the north in November/December, returning in April/May".

The second type of inter-island movement by caribou usually occurs sporadically in response to extreme snow and/or ice conditions that lead to widespread unavailability of forage. Serious forage restrictions brought on by unfavourable snow or ice conditions can occur on one or a few islands, while adjacent islands may be relatively free from such severe conditions. Peary caribou (and possibly all caribou) have retained displacement as a natural response to such situations. Thus, caribou often freely move long distances in search of new forage. In the Canadian Arctic Archipelago such movements often necessarily involve inter-island crossings over sea ice to find favourable forage on other islands.

Late winter conditions during spring breakup consistently lead to the formation of ground-fast ice over extensive areas of the islands. Such ice accumulation is greatest, and thus most severe and restrictive, where there is most vegetation per unit area. Snow depths are greater on protected, heavily vegetated sites, and deeper snow causes greater depths and longer durations of ground-fast ice there. Caribou respond at that time of the year by moving from relatively well vegetated sites to poorly vegetated, windblown sites. Although vegetation is sparse on exposed sites, it is available and the caribou can survive best there. In most years (even if most adult caribou survived) many or most breeding females would either produce nonviable neonates or subsequently fail to rear their young, if they could not move to available forage on exposed sites. In many places the simplest relief from such widespread detrimental conditions is through inter-island movement (e.g. from western Somerset Island winter-range to relief-sites on spring transitional range on eastern Prince of Wales Island). However, the spring condition of ground-fast ice accumulation and widespread forage unavailability is so consistent among years that it cannot be thought of as a sporadic event in the lives of Peary caribou. So, this springtime phenomenon should probably be considered as a common cause of the initiation and maintenance of traditional spring migrations from winter ranges to spring transitional relief ranges. If those spring transitional ranges necessitate inter-island movements, it will likely result in caribou having to remain on the island throughout the summer, before returning to traditional winter range in autumn. Perhaps the selection of calving areas by Peary caribou plays a major role in the choice of summering islands.

A third kind of movement, although not documented, may involve a sporadic inter- or intra-island movement by individuals or small social groups that can occur at any time of the year. Such movements probably arise either by chance or simply from a seemingly innate "restlessness" of caribou. Sea ice crossings, other than extended treks that greatly exceed time intervals between normal foraging periods, are essentially the same as land travel over snow covered terrain. Thus, sporadic events such as, severe storms, encounters with predators, exposures to new stimuli, or simply a drive to seek new range could trigger a chance sea ice crossing.

Traditional behaviour is not necessarily fixed in time or space, so changes in traditions should be expected over time, especially when influenced by significantly different climate. Traditions will continue as long as the results are favourable to the survival of the participants in the long run, or possibly at least neutral in their effects. Traditions such as inter-island migrations can be maintained by only a few individuals during periods of low densities, long after any real need for those movements ceases. In this way reestablishment of large-scale inter-island migrations can be readily reinitiated as densities increase to levels where individuals would benefit from such behaviour. An example is the recent resurgence of caribou movement, involving northward shifts of barren-ground caribou from the mainland to Victoria Island and Victoria Island caribou southward to Kent Peninsula and the Coppermine area (personal communication, A. Gunn). Also, widespread forage restriction (caused by spring ground-fast ice accumulations frequently experienced by Peary caribou) can sometimes cause high mortality regardless of existing density levels. Therefore, some caribou could benefit from seeking relief through inter-island movements to exposed spring transition ranges, even at low densities.

In conclusion, it appears that inter-island movements are beneficial to caribou in the Canadian Arctic Islands, and particularly to Peary caribou on the QEI, as follows:

(1) Inter-island migrations serve to, and are necessary to, maximize the seasonal use of the best ranges (in quantity and quality) that are available on two or more adjacent islands (or between or among the mainland and one or more islands) by the greatest number of caribou on a periodic basis.

(2) Inter-island movements at any time throughout the winter allow sporadic or periodic (spring) relief for large numbers of caribou from widespread forage unavailability.

(3) Thus, inter-island migrations and movements likely contribute strongly to maximizing the height and length of population highs and minimizing the depth and duration of population lows

Individuals of Peary caribou and their intergrades apparently lead a precarious existence in the Canadian Arctic Archipelago, particularly in the QEI. Those caribou could be threatened if human activities prevented them from making inter-island movements during winter. Under such conditions, Peary caribou on the QEI might only persist as remnants, if they could not respond by inter-island shifts to their sometimes extremely severe and always stringent winter surroundings. Caribou managers must think of these caribou as belonging to *inter-island populations* rather than island populations. This leads to the dire need for recognizing possible impacts of intensive ice-breaker activities that could be associated with tanker traffic in the Canadian High Arctic.

Undoubtedly, the most significant factor in the origin of Peary caribou and their evolutionary development in the Canadian Arctic Archipelago has been the ability to migrate long distances over sea ice and their continual use of inter-island sea ice crossings, both as periodic seasonal migrations and as sporadic movements. In fact, inter-island migrations and environmentally-forced movements (which we may view as "ecological manoeuvres" by Peary caribou to cope with and prosper in their harsh surroundings) have been, and will continue to be, the deciding factor in controlling gene flow and thus in shaping our taxonomic perception of their destiny - evolution to the level of a true species.

ACKNOWLEDGEMENTS

Investigations of inter-island movements of caribou in the Canadian Arctic Archipelago between 1972 and 1982 were supported by the Canadian Wildlife Service and Polar Continental Shelf Project (PCSP). I am most grateful to G.D. Hobson (PCSP) for his continued support of my studies. I gratefully acknowledge the assistance of the many field observers and my co-authors in these and related studies. I am especially indebted to Dr. A. Gunn (Department of Renewable Resources, Government of the Northwest Territories, Coppermine) for her assistance in many of these studies, especially for the critical debates regarding the value of inter-island movements to caribou.

REFERENCES

Amundsen, R. 1908. The North-West Passage, being the record of a voyage of exploration of the ship *Gjoa*. 2 volumes. A. Constable, London. 732 pp.

Anderson, R.M. 1913A. Arctic game notes. American Museum Journal 13:4-21.

______. 1913B. Report on the natural history collections of the expedition. In: Stefansson - My life with the Eskimo. Macmillan, New York. pp. 436-527.

______. 1920. (Evidence given by). Proceedings Royal Commission to Investigate the Possibilities of the Reindeer and Musk-ox Industry in Northern Canada. Volume 3:514-546.

______. 1922. Memorandum on barren ground caribou and musk-ox. In: Report of the Royal Commission to Investigate the Possibilities of the Reindeer and Musk-ox Industries in the Arctic and Sub-arctic Regions of Canada. Department of the Interior, Ottawa. 99 pp.

Armstrong, A. 1857. A personal narrative of the discovery of the North-West Passage. Hurst and Blackett, London. 616 pp.

Banfield, A.W.F. 1954. The role of ice in the distribution of mammals. Journal of Mammalogy 35:104-107.

______. 1961. A revision of the reindeer and caribou, genus *Rangifer*. National Museum of Canada Bulletin 177, Biological Series 66:1-137.

______. 1963. The post glacial dispersal of American caribou. Proceedings of the XVI International Congress of Zoology, Washington, D.C. 1:206.

Bernier, J.E. 1910. Report on the Dominion Government Expedition to the Arctic Islands and Hudson Strait on board the C.G.S. *Arctic* in 1908-1909. King's Printer, Ottawa. 529 pp.

Bissett, D. 1968. Resolute: an area economic survey. In: Lancaster Sound Survey. Volume II. Industrial Division, Department of Indian Affairs and Northern Development, Ottawa. 175 pp.

Burwash, L.T. 1931. Canada's western Arctic. Department of the Interior, Ottawa. 116 pp.

Chipman, K.G. 1920. (Evidence given by). Proceedings Royal Commission to Investigate the Possibilities of the Reindeer and Musk-ox Industry in Northern Canada. Volume 1:95-108.

Clarke, C.H.D. 1940. A biological investigation of the Thelon Game Sanctuary. National Museum Canada, Bulletin 96, Biological Series 25:1-135.

Collinson, R. 1889. Journal of H.M.S. *Enterprise*, on the expedition in search of Sir John Franklin's ships by Behring Strait, 1850-55. Edited by: T.B. Collinson. S. Low, Marston, Searle, and Rivington, London. 531 pp.

Degerbøl, M. 1957. The extinct reindeer of East-Greenland *Rangifer tarandus eogroenlandicus*, subsp. nov. compared with reindeer from other Arctic regions. Acta Arctica 10:1-66.

Fischer, C.A. and E.A. Duncan. 1976. Ecological studies of caribou and muskoxen in the Arctic Archipelago and northern Keewatin, 1975. Renewable Resources Consulting Services Ltd., Edmonton. Report for the Polar Gas Environmental Program 1975. 194 pp.

Franklin, J. 1823. Narrative of a journey to the shores of the Polar Sea in the years 1819, 20, 21 and 22 with an appendix on various subjects relating to science and natural history. John Murray, London. 768 pp.

Freeman, M.M.R. 1974. Environmental report, Bathurst Island, N.W.T. 1974: Part 1. Caribou. Inuit Land Use and Occupancy Project. 12 pp. (typescript).

______. 1975. Assessing movement in an Arctic caribou population. Journal of Environment Management 3:251-257.

Gibson, W. 1932. Some further traces of the Franklin retreat. Journal of the Royal Geographical Society 79(5):402-408.

Gilder, W.H. 1881. Schwatka's search: sledging in the Arctic in quest of the Franklin records. C. Scribner's, New York. 316 pp.

Godsell, P.H. 1937. The blond Eskimos and the created want. Natural History 39:285-289.

______. 1943. Arctic trader. G.P. Putnam's, New York. 329 pp.

Gunn, A. and F.L. Miller. 1980. Responses of Peary caribou cow-calf pairs to helicopter harassment in the Canadian High Arctic. In: Proceedings of the 2nd International Reindeer/Caribou Symposium, Røros, Norway, 1979. Edited by: E. Reimers, E. Gaare, and S. Skjenneberg. Direktoratet for vilt og ferskvannsfisk, Trondheim. pp. 497-507.

______. 1983. Size and status of an inter-island population of Peary caribou. Acta Zoological Fennica 175:153-154.

Hakala, A.V.K., H. Staaland, E. Pulliainen, and K.H. Røed. 1985. Taxonomy and history of arctic island reindeer with special reference to Svalbard reindeer. Aquilo Series Zoologica 23:1-11.

Harington, C.R. 1970. A postglacial muskox (*Ovibos moschatus*) from Grandview, Manitoba, and comments on the zoogeography of *Ovibos*. National Museum of Natural Sciences, Publications in Palaeontology 2:1-13.

______. 1971. Ice age mammals in Canada. Arctic Circular 22(2):66-89.

______. 1979. Quaternary vertebrate faunas of Canada and Alaska and their suggested chronological sequence. Syllogeus 15:1-105.

______. 1982. A.H. Joy (1887-1932). Arctic Profiles, Arctic 35(4):558-559.

Hoare, W.H.B. 1920. (Evidence given by). Proceedings Royal Commission to Investigate the Possibilities of the Reindeer and Musk-ox Industry in Northern Canada. Volume 1:76-86.

______. 1925. Report of investigations [affecting Eskimo and wild life, District of Mackenzie] 1924-25. Northwest Territories and Yukon Branch, Department of the Interior, Ottawa. 15 pp.

______. 1927. Report of investigations [affecting Eskimo and wild life, District of Mackenzie] 1925-1926, together with general recommendations. Northwest Territories and Yukon Branch, Department of the Interior, Ottawa. 44 pp.

Jenness, D. 1920. (Evidence given by). Proceedings Royal Commission to Investigate the Possibilities of the Reindeer and Musk-ox Industry in Northern Canada. Volume 1:155-167.

______. 1922. The life of the Copper Eskimos. Report Canadian Arctic Expedition 1913-18. Volume 12 (Part A):1-227.

______. 1928. The people of the twilight. Macmillan, New York. 247 pp.

Johansen, F. 1920. (Evidence given by). Proceedings Royal Commission to Investigate the Possibilities of the Reindeer and Musk-ox Industry in Northern Canada. Volume 1:121-144.

Lønø, O. 1959. Reinen pa Svalbard. Meddelelser Norske Polarinstitutt, Oslo 83:1-31.

Macpherson, A.H. 1959. The caribou of Boothia Peninsula. Canadian Wildlife Service, Edmonton. 16 pp. (Unpublished report).

______. 1961. On the abundance and distribution of certain mammals in the western Canadian Arctic Islands in 1958-59. Arctic Circular 14(1):1-16.

______. 1965. The origin of diversity in mammals of the Canadian Arctic tundra. Systematic Zoology 14(3):153-173.

Macpherson, A.H. and T.H. Manning. 1959. The birds and mammals of Adelaide Peninsula, Northwest Territories. National Museum of Canada, Bulletin 161:1-63.

Manning, T.H. 1960. The relationship of the Peary and barren-ground caribou. Arctic Institute of North America, Technical Paper 4:1-52.

Manning, T.H. and A.H. Macpherson. 1958. The mammals of Banks Island. Arctic Institute of North America, Technical Paper 2:1-74.

______. 1961. A biological investigation of Prince of Wales Island, N.W.T. Transactions of the Royal Canadian Institute 33(2):116-239.

McEwen, E.H. 1955. A biological survey of the west coast of Banks Island - 1955. Canadian Wildlife Service, Edmonton. 56 pp. (Unpublished report).

M'Clintock, F.L. 1859. The voyage of the *Fox* in the Arctic seas. A narrative of the discovery of the fate of Sir John Franklin and his companions. John Murray, London. 403 pp.

M'Clure, R. 1856. The discovery of the North-West Passage by H.M.S. *Investigator* 1850, 1851, 1852, 1853, 1854. Edited by: S. Osborn. M.G. Hurtig, Edmonton. 405 pp. Reprint 1969.

M'Dougall, G.F. 1857. The eventful voyage of H.M. Discovery ship *Resolute* to the Arctic regions in search of Sir John Franklin and the missing crews of H.M. Discovery ships *Erebus* and *Terror*, 1852, 1853, 1854. Longman's, London. 529 pp.

Meldgaard, M. 1986. The Greenland caribou - zoogeography, taxonomy, and population dynamics. Meddelelser om Grønland, Bioscience 20:1-88.

Miller, F.L., E.J. Edmunds, and A. Gunn. 1982. Foraging behaviour of Peary caribou in response to springtime snow and ice conditions. Canadian Wildlife Service, Occasional Paper 48:1-39.

Miller, F.L. and A. Gunn. 1978. Inter-island movements of Peary caribou south of Viscount Melville Sound, Northwest Territories. Canadian Field-Naturalist 91:327-333.

______. 1979. Responses of Peary caribou and muskoxen to helicopter harassment. Canadian Wildlife Service, Occasional Paper 40:1-90.

______. 1980. Inter-island movements of Peary caribou (*Rangifer tarandus pearyi*) south of Viscount Melville Sound and Barrow Strait, Northwest Territories, Canada. In: Proceedings of the 2nd International Reindeer/Caribou Symposium, Røros, Norway, 1979. Edited by: E. Reimers, E. Gaare, and S.. Skjenneberg. Direktoratet for vilt og ferskvannsfisk, Trondheim. pp. 99-114.

Miller, F.L. and H.P.L. Kiliaan. 1980A. Inter-island movements of Peary caribou in the Prince of Wales Island-Somerset Island-Boothia Peninsula complex, Northwest Territories, May-July 1979. Canadian Wildlife Service, Progress Notes 107:1-7.

______. 1980B. Some observations on springtime snow/ice conditions on 10 Canadian High Arctic islands - and a preliminary comparison of snow/ice conditions between eastern Prince of Wales Island and western Somerset Island, N.W.T., 5 May - 2 July 1979. Canadian Wildlife Service, Progress Notes 116:1-11.

______. 1981. Inter-island movements of Peary caribou in the Prince of Wales Island-Somerset Island-Boothia Peninsula complex, Northwest Territories, June 1980. Canadian Wildlife Service, Progress Notes 120:1-7.

Miller, F.L., R.H. Russell, and A. Gunn. 1977A. Distributions, movements and numbers of Peary caribou and muskoxen on western Queen Elizabeth Islands, Northwest Territories, 1972-74. Canadian Wildlife Service, Report Series 40:1-55.

______. 1977B. Interisland movements of Peary caribou (*Rangifer tarandus pearyi*) on western Queen Elizabeth Islands, Arctic Canada. Canadian Journal of Zoology 55:1029-1037.

O'Neill, J.J. 1920. (Evidence given by). Proceedings Royal Commission to Investigate the Possibilities of the Reindeer and Musk-ox Industry in Northern Canada. Volume 1:36-48.

Parry, W.E. 1821. Journal of a voyage for the discovery of a North-West Passage from the Atlantic to the Pacific; performed in the years 1819-1820, in His Majesty's ships *Hecla* and *Griper*, under the orders of William Edward Parry ... with an appendix containing scientific and other observations. John Murray, London. 309 pp.

Rae, J. 1852. Journey from Great Bear Lake to Wollaston Land. Journal of the Royal Geographical Society 22:73-82.

Rand, A.L. 1954. The ice age and mammal speciation in North America. Arctic 7:31-35.

Rasmussen, K. 1927. Across Arctic America. Narrative of the Fifth Thule Expedition. G.P. Putnam's, New York. 388 pp.

Riewe, R.R. 1978. The utilization of wildlife in the Jones Sound region by the Grise Fiord Inuit. In: Truelove Lowland, Devon Island, Canada: a High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 621-644.

Røed, K.H., H. Staaland, E. Broughton, and D.C. Thomas. 1986. Transferrin variation in caribou (*Rangifer tarandus* L.) on the Canadian Arctic Islands. Canadian Journal of Zoology 64:94-98.

Simpson,T. 1843. Narrative of the discoveries on the north coast of America effected by the officers of the Hudson's Bay Company during the years 1836-39. R. Bentley, London. 419 pp.

Stefansson, V. 1913A. Victoria Island and the surrounding seas. Bulletin of the American Geographical Society 45:93-106.

______. 1913B. My life with the Eskimo. Macmillan, New York. 538 pp.

______. 1914. The Stefansson-Anderson arctic expedition of the American Museum; preliminary ethnological report. Anthropology Paper American Museum Natural History 14(1):1-395.

______. 1920. (Evidence given by). Proceedings Royal Commission to Investigate the Possibilities of the Reindeer and Musk-ox Industry in Northern Canada. Volume 1:76-280.

______. 1921. The friendly Arctic. Macmillan, New York. 784 pp.

Storkerson, S.T. 1920. (Evidence given by). Proceedings Royal Commission to Investigate the Possibilities of the Reindeer and Musk-ox Industry in Northern Canada. Volume 1:255-280.

Tener, J.S. 1963. Queen Elizabeth Islands game survey, 1961. Canadian Wildlife Service, Occasional Paper 4:1-50.

Thomas, D.C. and P. Everson. 1982. Geographic variation in caribou on the Canadian Arctic Islands. Canadian Journal of Zoology 60:2442-2454.

Thompson, D.C. and C.A. Fischer. 1980. Numbers and distribution of caribou on the Boothia Peninsula, Northwest Territories. Canadian Field-Naturalist 94:171-174.

Vibe, C. 1967. Arctic animals in relation to climatic fluctuations. Meddelelser om Grønland 170(5):1-227.

Willemsen, G.F. 1983. Osteological measurements and some remarks on the evolution of the Svalbard reindeer, *Rangifer tarandus platyrhynchus*. Zeitschrift für Saügetierkunde 48:175-185.

Wollebaek, A. 1926. The Spitzbergen reindeer (*Rangifer tarandus spitsbergensis*). Resultater av de Norske Statunderstottede Spitsbergenekspeditioner 1(4):1-71.

Youngman, P.M. 1975. Mammals of the Yukon Territory. National Museum of Natural Sciences, Publications in Zoology 10:1-192.

Caribou Study
Aug. 83
Baffin Island
Brenda Carter

Illustrated by Brenda Carter

MUSKOX (Ovibos moschatus Zimmermann) POPULATIONS ON THE NORTHEASTERN COAST OF DEVON ISLAND

Donald L. Pattie[1]

Abstract: Earlier estimates of muskox numbers along the northeastern coast of Devon Island were compared with 1984 to 1987 surveys over five lowlands in that region. A 10-year record of muskox populations on Truelove Lowland is presented for the years 1978-1987. Density on lowland habitat suitable for muskox grazing varied from a high of 0.9 muskox km^{-2} in 1973 to a low of 0.3 km^{-2} in 1987. Muskox population density on Truelove Lowland during the second half of July ranged from a high of 2.5 km^{-2} in 1980 to a low of 0.2 km^{-2} in 1985 and 1986. Herd composition, consisting of numbers of calves, yearlings and (where possible) bulls and cows, is presented for the years 1984-1987. High calf mortality in some years and fluctuating natality were indicated. A population decline of one third followed the winter of 1984-1985.

Résumé: Les premières évaluations du nombre de boeufs musqués de la côte nord-est de l'île Devon ont été comparées avec les études faites de 1984 à 1987 sur cinq terres basses de cette région. On présente des données sur dix ans (1978-1987) des populations de boeufs musqués dans les basses-terres de Truelove. La densité sur les basses-terres adaptées au pâturage de l'espèce a varié d'un maximum de 0,9 boeuf musqué par km^2 en 1973 à un minimum de 0,3/km^2 en 1987. Pendant la dernière moitié de juillet, la densité de population des boeufs musqués dans les basses-terres de Truelove est passée d'un maximum de 2,5 km^2 en 1980 à un minimum de 0,2/km^2 en 1985 et 1986. On donne, pour les années 1984 à 1987, la composition de la harde, c'est-à-dire le nombre de veaux, le nombre de bêtes d'un an et (quand c'est possible) le nombre d'adultes mâles et femelles. On a trouvé un taux de mortalité élevé chez les veaux pour certaines années et une natalité qui varie. Un déclin d'un tiers de population de boeufs musqués a suivi l'hiver 1984-1985.

INTRODUCTION

Truelove Lowland on Devon Island's northeastern coast has been the site of some of the most intensive long-term scientific studies ever undertaken in the Canadian Arctic Islands. Detailed descriptions of both the physical and biotic features of the lowland appeared in Bliss (1977). Muskoxen, the largest terrestrial herbivores on the island, occupy the coastal lowlands. They have been the subject of various studies since the early 1960s. Harington (1964) collected information from Royal Canadian Mounted Police records and other sources about muskox numbers on the northeastern coast of Devon Island from 1908 to 1960. His published estimates ranged from a low of 20 in 1929 to a maximum of 100 in 1937. Tener (1965) estimated 200 muskox for all of Devon Island. Freeman (1971) estimated the muskox population for the lowlands along the entire shore of Bear Bay (Figure 1) at 230-300. Hubert (1977) carried out intensive counts on five adjacent lowlands between Sverdrup Inlet to the west, and Sverdrup Glacier to the east, from 1970 to 1973. The area Hubert surveyed was considerably smaller than the area Freeman covered, yet the highest of

---

[1] Northern Institute of Technology, 11762-106 Street, Edmonton, Alberta T5G 2R1

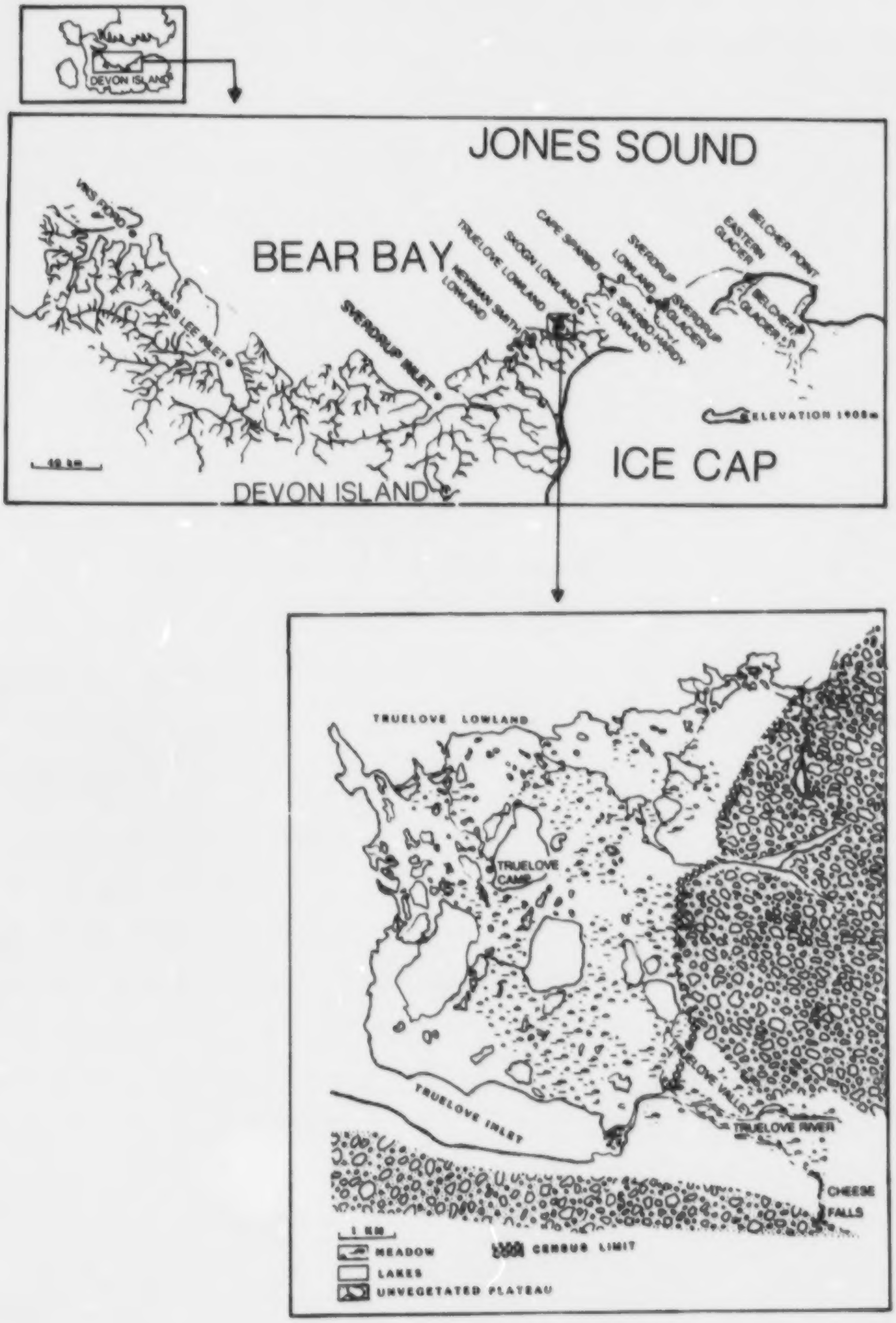

DEVON ISLAND
JONES SOUND
BEAR BAY
VAS FIORD
THOMAS LEE INLET
SVERDRUP INLET
NEWMAN SMITH LOWLAND
TRUELOVE LOWLAND
SKOGN LOWLAND
CAPE SPARBO
SPARBO-HARDY LOWLAND
SVERDRUP LOWLAND
SVERDRUP GLACIER
EASTERN GLACIER
BELCHER POINT
BELCHER GLACIER
ELEVATION 1900m
ICE CAP
10 km
DEVON ISLAND
TRUELOVE LOWLAND
TRUELOVE CAMP
TRUELOVE INLET
TRUELOVE VALLEY
TRUELOVE RIVER
CHEESE FALLS
1 KM
MEADOW
LAKES
UNVEGETATED PLATEAU
CENSUS LIMIT

FIGURE 1: **Places on the northeast coast of Devon Island, Northwest Territories, that are mentioned in the text.**

Hubert's counts, 287 in 1973, approached the maximum Freeman had reported. Hubert (1977) also investigated herd composition and movements.

An attempt to count all muskoxen on Truelove Lowland and in Truelove Valley was undertaken from 1978 to 1987, and most or all of the adjacent lowlands where Hubert counted muskoxen were again surveyed during 1984-1987. Together these data provide the longest records of muskox population trends in the Canadian Arctic.

METHODS

The 1978-1987 Truelove muskox counts were conducted during the second half of July. A virtually complete coverage of Truelove Lowland was achieved by having observers walk abreast 100 m apart along predetermined routes marked on a detailed map. Muskoxen in Truelove Valley were typically counted soon after, using a less rigorous technique which involved counting all muskoxen seen during a walk to and from Cheese Falls (Figure 1).

Hubert (1977) used both fixed-wing aircraft and helicopters for his surveys. All of the 1984-1987 data were obtained during helicopter surveys. On these surveys three observers recorded numbers and, where possible, the sex and age of muskoxen seen. The helicopter was flown in a grid pattern for the 1984-1987 counts with 400 m between lines at an altitude of 30-40 m above the surface. Because the 1984-1987 censuses were all conducted during the second half of July, Hubert's July 1970 and 1971 records were selected for comparison. Since he did no July surveys in 1972, we used his 8 May figures, and the 1973 data were from a 16 August survey.

We did not attempt to distinguish the sex of calves or yearlings. Often, because of distance or the orientation of the adults, their sex could not be identified either. They were recorded "adults - sex not determined".

RESULTS

The annual muskox counts for the 58 km^2 Truelove Lowland - Truelove Valley region are reported in Table 1. Presumably the results in some years were affected by significant population movements from or to other nearby lowlands.

TABLE 1: SEX, AGE AND DENSITY OF MUSKOXEN ON THE 58 km^2 TRUELOVE LOWLAND - TRUELOVE VALLEY REGION BASED UPON WALKED POPULATION SURVEYS (1978-1987).

YEAR	ADULT MALES	ADULT FEMALES	YEARLINGS	CALVES	ADULTS, SEX NOT DETERMINED	TOTAL	ESTIMATED DENSITY (MUSKOXEN PER KM^{-2})
1978	17	11	5	6	18	57	1.0
1979	23	23	5	17	10	78	1.4
1980	3	5	0	26	111	145	2.5
1981	9	-	3	3	48	63	1.1
1982	12	4	-	1	22	39	0.7
1983	-	-	-	2	47	49	0.8
1984	25	17	-	11	-	53	0.9
1985	3	4	-	1	5	13	0.2
1986	5	3	-	0	4	12	0.2
1987	2	9	1	7	-	19	0.3

TABLE 2: MUSKOX POPULATIONS OF FIVE OF DEVON ISLAND'S CONTIGUOUS NORTH COAST LOWLANDS OBSERVED DURING AERIAL POPULATION SURVEYS (1970-1973, 1984-1987)[1].

YEAR	AREA						ESTIMATED DENSITY (MUSKOXEN PER KM^2)
	Newman Smith (139 km^2)	Truelove (58 km^2)	Skogn (15 km^2)	Sparbo-Hardy (66 km^2)	Sverdrup (22 km^2)	Total	
1970	23	17	10	17	65	132	0.4
1971	10	22	13	21	50	116	0.4
1972	29	70	1	99	50	249	0.8
1973	57	27	9	167	18	278	0.9
1984	87	13	10	36	42	188	0.6
1985[2]	-	8	4	40	19	71	0.4
1986	48	12	2	24	57	143	0.5
1987	11	19	12	25	9	76	0.3

[1] 1970-1973 data from Hubert (1977).

[2] No count could be made on Newman Smith Lowland in 1985; density reflects area surveys.

Aerial survey data from 1984 to 1987 are listed (Table 2), together with selected results of aerial surveys conducted in 1970-1973 by Hubert (1977). The zones surveyed from east to west include: Sverdrup, Sparbo-Hardy, Skogn, Truelove and Newman Smith lowlands (Figure 1).

Table 3 lists the composition of the various lowland muskox herds to the degree it could be determined from a helicopter. Newman Smith Lowland could not be surveyed in 1985 because of poor weather when the helicopter was available. The density calculation for 1985 is based upon the areas counted.

DISCUSSION

The annual changes in muskox densities might be associated with major movements, differing patterns of habitat use, increases caused by births or immigration, and decreases associated with deaths or emigration. While herd movements from one to another of the lowlands surveyed occurs (Hubert 1977), it is unlikely that there was significant movement to others as there are no large ones nearby. A few small coastal lowlands exist between Sverdrup Glacier and Eastern Glacier (Figure 1), and Hubert (1977) counted a maximum of 13 muskoxen on them in May 1973. Movement to or from that area cannot, however, explain the amplitude of change recorded in Table 2. Population changes seen in Table 1 more likely reflect movements between the contiguous lowlands, as herds occasionally move from one lowland to another. Muskoxen rarely range far up onto the largely-unvegetated plateau in the vicinity of the nearby Devon Island Ice Cap. During a summer helicopter flight, two muskox cows, each with a calf, were seen near the ice cap at least 9 km from the nearest lowland. Since there was less than 1% vegetative cover on that plateau, I suspect they went there to escape mosquitoes or predators, and not to feed. Muskoxen occasionally cross significant expanses of sea ice, for in June 1970 we saw a herd of five on Bear Bay a few kilometres from shore (see Miller, this volume, regarding caribou crossing sea ice). Thus there could be some emigration or immigration. Such movements would help to explain the increase Hubert (1977) reported. Another reasonable explanation is a failure to observe animals that may have been associated with rocky outcrops during some of Hubert's aerial surveys. Rocks and resting muskoxen can be confused easily.

TABLE 3: RESULTS OF JULY AERIAL MUSKOX CENSUS ON FIVE ADJACENT DEVON ISLAND NORTH COAST LOWLANDS FROM 1984-1987.

LOWLAND AND (AREA)	1984	1985	1986	1987
Newman Smith (139 km²)				
Males	53	-	25	4
Females	23	-	20	6
Yearlings	2	-	3	1
Calves	9	-	-	-
Sex undetermined; more than 1 year old	-	-	-	-
TOTAL	87	-	48	11
Truelove (58 km²)				
Males	-	3	5	2
Females	-	4	3	9
Yearlings	-	-	-	1
Calves	3	1	-	7
Sex undetermined; more than 1 year old	10	-	4	-
TOTAL	13	8	12	19
Skogn (15 km²)				
Males	-	3	2	3
Females	-	1	-	6
Yearlings	-	-	-	-
Calves	3	-	-	3
Sex undetermined; more than 1 year old	7	-	-	-
TOTAL	10	4	2	12
Sparbo-Hardy (66 km²)				
Males	-	15	10	7
Females	-	18	5	9
Yearlings	-	-	-	1
Calves	7	2	-	8
Sex undetermined; more than 1 year old	29	5	9	-
TOTAL	36	40	24	25
Sverdrup (22 km²)				
Males	-	15	28	3
Females	-	2	23	5
Yearlings	-	1	1	-
Calves	9	1	5	1
Sex undetermined; more than 1 year old	33	-	-	-
TOTAL	42	19	57	9
TOTAL FOR ALL LOWLANDS	188	71[1]	143	76

[1] Does not include Newman-Smith Lowland, which was not surveyed in 1985.

The major declines in numbers were related to mortality - apparently accidents, predation and starvation are the most important agents. Muskox predation by wolves and polar bears occurred, and a few accidental deaths were observed (Pattie 1986). However, examples of predation or accident-related deaths were too few to explain the decline in muskox populations from 1984-1987. Based on carcasses or remains examined, starvation appeared to be implicated in most deaths. Detailed analysis of femur fat content or other criteria of body condition at the time of death were not performed, but obviously many of the animals were emaciated. This evidence is corroborated by our observations that scavenging bears, wolves, and foxes often chewed a hole near the back of the ribs and ate only the liver, heart, and lungs, leaving the gastro-intestinal tract, skeletal muscle and bones. Evidently the scavengers did not find that the gain from consuming the rest of the carcass compensated for the effort required to strip the frozen remains.

Hubert (1977) summarized the frequency and severity of mortality, and suggested that starvation during winter was a key factor. Parker *et al.* (1975) also studied Canadian Arctic Islands muskox populations. They suggested starvation was related to: (1) greater than usual snow accumulation in winter feeding areas; (2) icing conditions that made feed unavailable; and (3) reduced production or overharvesting of vegetation. Although only summer weather records are available from 1978-1987, no indication of extreme snow accumulation or icing was noted during that time.

Snow accumulation appeared scant in 1984-1985 and 1985-1986, during which periods the muskox population declined to half the 1984 level.

Empirical data would be required to determine whether overgrazing of vegetation occurred, and such data are not available. Muc (1977) determined that the growth period for sedges and grasses on Truelove Lowland was almost constant, regardless of summer climatic variation, and noted that higher temperatures resulted in increased net production throughout the sedge-moss meadows. Most plant growth took place during July. Svoboda (1977) found that increased plant production on drier Truelove sites was associated with the wettest summers. His data showed that the greatest production of plant biomass was associated with the wettest, but coldest, of the four seasons he studied.

Seemingly the quantity of available winter muskox forage is most affected by summer temperature, and summer forage abundance by the frequency of summer precipitation. Since winter at these latitudes lasts about nine months, summer temperatures may have a disproportionate effect on the muskox population. Summer temperatures show considerable variation. In 1973 the average July temperature was 9.6°C, the highest that has been recorded. In contrast, the average July temperature in 1986, when muskox populations were declining, was 3.1°C. Further study to determine the interaction of climatic factors and muskox populations is needed.

Almost no muskox forage grows above an altitude of 200 m on northeastern Devon Island. The area between the point where Sverdrup Glacier drops to Jones Sound on the east and Sverdrup Inlet joins Bear Bay in the west that is below 200 m has an area of approximately 300 km^2. Of this, only about 50 km^2 is well vegetated meadow. Hubert (1977) reported that muskoxen commonly used these meadows. He recognized that hummocky sedge-meadows with an average available standing crop of 62 g m^{-2} were grazed most, followed by frost-boil sedge-moss meadows that had an average available standing crop of 51 g m^{-2}. The significance of Truelove Lowland to the northeastern Devon Island muskox population is obvious for 17 km^2 (34%) of the 50 km^2 of meadow is there. However, Hubert's (1977) findings revealed that the bulk of grazing on these meadows took place during the period of continuous darkness, maximum snowcover, and the lowest ambient temperatures. Our counts took place during the period of continuous light, minimum snowcover, and maximum ambient temperatures when, I suspect, the bulk of grazing was concentrated in areas where vegetation was less abundant but perhaps more palatable. The significance of this is that it is *easier* to see muskoxen in meadows than in the broken land and rock outcrops they frequent in summer. Practically all muskoxen were seen by the observers walking in the Truelove Lowland, and most were counted in Truelove Valley. No doubt some were missed during surveys from aircraft of the other lowlands. Thus, the counts reported must be regarded as minimal. However, it is doubtful that the numbers not tallied could account for the declines seen during 1984-1987 (Table 2).

One indication of population stability is the annual survival of calves to yearlings. Thirty-one calves were counted in 1984. Of this cohort, only one survived to be counted as a yearling in 1985. In addition, only four calves were seen in 1985 suggesting a crash had occurred like that reported by Parker *et al.* (1975) for Melville, Bathurst, and Byam Martin islands. Parker's group reported high mortality rates, low pregnancy rates, and emaciated animals which, based upon rumen contents, had been feeding on dry habitats with low productivity. The rumen contents were what one would expect from animals grazing the beach ridges of Truelove Lowland rather than the more productive sedge-meadows. Unfavourable conditions for muskox on Devon Island may have persisted through the winter of 1985-1986, for in 1986 we saw only five calves. These data support Hubert's (1977) contention than muskoxen exhibit "occasional increased mortality combined with fluctuating natality".

Observations suggest the muskox population on northeastern Devon Island ranged from a maximum of about 275 in 1973 to a minimum near 75 in 1987. There was no indication that predation or accidents were responsible for major population losses. Carcasses we found were emaciated, suggesting that starvation plays an important part in population regulation.

The population is lightly hunted. The Inuit of Grise Fiord have an annual quota of 27 muskoxen, of which only four males may be taken on northeastern Devon Island. The quota has always been filled.

The Truelove Lowland population exhibits an even greater amplitude of fluctuation than the entire coastal population (Table 1). From a maximum of 145 in 1980, the numbers on Truelove declined to 12 in 1986. Herd movements from or to adjacent lowlands probably played the most important role in these changes. These movements could have been either the seasonal type Hubert (1977) noted, or movements he reported that seemed to be associated with the appearance of polar bears. However, since the surveys were conducted about the same time each year, and there was evidence of bear predation on only four muskoxen between 1979 and 1984, factors other than these two are suggested.

Data presented here support the findings of Parker *et al.* (1975) and those of Hubert (1977), who noted that muskox populations are subject to great fluctuations in both birth and death rates. Apparently the northeastern Devon Island population reached the lowest level since 1970 in 1987. Further study of the role of weather and food availability in muskox population regulation is needed.

ACKNOWLEDGEMENTS

This research was supported by Polar Continental Shelf Project as project 111-80. The Arctic Institute of North America assisted with transportation and provided technical help and accommodation at its field station. Space does not permit me to thank individually all who assisted me in the counts over the years, but their work is appreciated. Special thanks to Colleen Harlton and Jim Trask who, together, directed the work in 1987.

REFERENCES

Bliss, L.C. (Editor). 1977. Truelove Lowland, Devon Island, Canada: a High Arctic ecosystem. University of Alberta Press, Edmonton. 716 pp.

Freeman, M.M.R. 1971. Population characteristics of muskoxen in the Jones Sound region of the Northwest Territories. Journal of Wildlife Management 35(10):103-108.

Harington, C.R. 1964. Remarks on Devon Island muskoxen. Canadian Journal of Zoology 42:79-86.

Hubert, B.A. 1977. Estimated productivity of muskox on Truelove Lowland. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press. Edmonton. pp. 467-491.

Muc, M. 1977. Ecology and primary production of sedge-moss communities. In: Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss. University of Alberta Press, Edmonton. pp. 157-184.

Parker, G.R., D.C. Thomas, E. Broughton, and D.R. Gray. 1975. Crashes of muskox and Peary caribou populations in 1973-74 on the Parry Islands, Arctic Canada. Canadian Wildlife Service, Progress Notes 56:1-10.

Pattie, D.L. 1986. Muskox density and calf numbers on Devon Island's north coast. Journal of Mammalogy 67(1):190-191.

Svoboda, J. 1977. Ecology and primary production of raised beach communities. In Truelove Lowland, Devon Island, Canada: A High Arctic Ecosystem. Edited by: L.C. Bliss, University of Alberta Press, Edmonton. pp. 185-216.

Tener, J.S. 1965. Muskoxen in Canada. Canadian Wildlife Service, Monograph Series 2:1-166.

NURSING BEHAVIOUR OF ARCTIC HARES (Lepus arcticus)

Aniśkowicz, B.T.,[1] H. Hamilton[2], D.R. Gray[3], and C. Downes[4]

Abstract: Nursing behaviour in three arctic hare (*Lepus arcticus*) families was studied at Polar Bear Pass, Bathurst Island, and Sverdrup Pass, Ellesmere Island during the summers of 1986 and 1987. Additional information was collected at Bathurst Island between 1968 and 1985 and at Borup Fiord, Ellesmere Island in 1988.

Three female hares nursed their three to five young at mean intervals of 19 hours 48 minutes, 18 hours 47 minutes and 18 hours 36 minutes. The young arrived near the nursing site singly or in groups, and congregated 21-90 minutes before their mother arrived. Nursing commenced immediately after the female's arrival. The duration of each nursing bout was short (range: 1-4 minutes). Occasionally, one or several of the young arrived late and missed the nursing. In several instances, when the young were up to four weeks old, the female, while still in the nursing area, allowed a leveret who arrived late to begin nursing as much as 9 minutes after the group suckle had ended. In one case only were some leverets allowed to resuckle. The female ended the nursing bout by hopping away. During the first several weeks after birth the female pulled away from the young immediately after nursing, but remained at the nursing site or close to it. As the young became older, the female quickly left the immediate vicinity of the nursing site when nursing stopped. In early summer the young hares dispersed rapidly after nursing but stayed near the nursing site, gradually increasing their range to an observed maximum of about 1 km in mid-August. Leverets gradually increased the amount of time they spent accompanying the female until, during August, they remained with her for up to 1.9 hours after nursing. Young hares occasionally remained together between nursing bouts. The young were weaned in the second or third week of August at 8-9 weeks old.

Résumé: On a étudié le comportement d'allaitement de trois familles de lièvres arctiques au col de Polar Bear, île Bathurst, et au col de Sverdrup, île Ellesmere, pendant les étés 1986 et 1987. On a également recueilli des renseignements supplémentaires provenant de l'île Bathurst entre 1968 et 1985 et du fjord Borup, îles Ellesmere, en 1988.

Trois femelles lièvres (hases) allaitaient trois à cinq petits à intervalles moyens de 19 heures 48 minutes, 18 heures 47 minutes et 18 heures 36 minutes. Les petits arrivaient près du lieu d'allaitement seuls ou en groupes et se rassemblaient de 21 à 90 minutes avant que leur mère n'arrive. L'allaitement commençait dès l'arrivée de la mère. La durée de chacune des périodes d'allaitement était courte (1 à 4 minutes). Parfois, un ou plusieurs petits arrivaient en retard et manquaient l'allaitement. Dans plusieurs cas, lorsque les petits avaient moins de 4 semaines, la femelle, qui se trouvait encore près du lieu d'allaitement, permettait à un levraut en retard de téter, même 9 minutes après que les autres avaient terminé. Dans un cas, la femelle a permis à la portée au complet de se faire allaiter une seconde fois. La hase terminait la période d'allaitement en s'éloignant par bonds. Pendant les premières semaines après la naissance, elle se retirait immédiatement après l'allaitement, mais restait sur les lieux ou à proximité. Lorsque les levrauts vieillissaient, la femelle quittait rapidement les abords du lieu d'allaitement dès la fin de la tétée. En début d'été, les jeunes lièvres se dispersaient vite après l'allaitement, mais restaient à proximité, s'éloignant graduellement, jusqu'à un maximum observé d'environ 1 km à la mi-août. Les petits accompagnaient leur mère de plus en plus longtemps jusqu'à ce qu'au mois d'août ils restent avec elle après l'allaitement pendant 1,9 heures. Quelques fois les levrauts demeuraient ensemble entre les périodes d'allaitement. Les petits étaient sevrés dans la deuxième ou la troisième semaine du mois d'août, ils étaient alors âgés de 8 à 9 semaines.

INTRODUCTION

Although arctic hares (*Lepus arcticus*) are widely distributed throughout northern Canada, including the Arctic Islands, they have not been studied extensively. Several studies have been conducted on their distribution in Newfoundland (Bergerud 1967; Hearn *et al.* 1987; Mercer *et al.* 1981), demography (Hearn *et al.* 1987), morphology (Parker 1977; Walkinshaw 1947) and population dynamics (Bergerud 1967; Lloyd 1981; Mercer *et al.* 1981). Although

---

[1] R.R. #4, Shawville, Quebec J0X 2Y0
[2] Box 412, Osgoode, Ontario K0A 2W0
[3] Zoology Division, National Museum of Natural Sciences, Ottawa, Ontario K1P 6P4
[4] 197 Glebe Avenue, #4, Ottawa, Ontario K1A 2C4

a few studies describe basic behaviour in this species (Bonnyman 1975; Parker 1977; Walkinshaw 1947), there is very little information on reproduction (Parker 1977; Walkinshaw 1947; Hampson 1968).

Research on other species of *Lepus* indicate that parental care, other than nursing, is virtually non-existent. Female brown hares (*L. europaeus*) (Broekhuizen and Maaskamp 1980) associate with their young only during nursing, which occurs once every 24 hours, soon after sunset. Shortly before nursing, young hares come to the nursing site from different directions and wait in a group. Within-litter variation in time of arrival is small. Very young leverets normally wait for their mother at the place of birth, which serves as the gathering-place, but as they get older they may go to meet the female who usually arrives from the same direction on successive evenings. Consequently, the nursing place gradually shifts. The female sits in an upright posture during nursing, which lasts only a few minutes. Duration of nursing bouts decreases as leverets age. Bouts are ended by the female jumping away from her young. Having nursed once, the female refuses all resuckling attempts. After nursing, the female leaves and the young disperse. The distance over which they range increases with age. Young hares nibble on vegetation from an age of four days onwards, and are weaned at 3-10 weeks, depending on whether they are a first or last litter.

Rongstad and Tester (1971) reported similar behaviour in the snowshoe hare (*L. americanus*). The young assembled 5-10 minutes before the arrival of the female and nursed for up to 10 minutes.

Both studies suggest that the nursing regime is based on cues from the 24-hour light-cycle.

Very little information is available on parental care in *L. arcticus*. Pedersen (1962) mentions that female hares paid close attention to their leverets during the first two or three days after birth and were reluctant to leave them. Hampson (1968) states that a nursing arctic hare on Bathurst Island returned to her leverets at long intervals and nursed them briefly - three minutes in one case. He reports a nursing bout observed at close range. After nursing, the young scattered in all directions. In one instance a leveret followed the mother for about 3 m before leaving her. The female departed abruptly after nursing ended and ran long distances before stopping to feed. Hampson did not observe a single case of the female feeding in the vicinity of her leverets, and noted that only once she dozed about 600 m from the young. He reported that 9-10 day-old leverets ate some fresh vegetation.

The present study gives details on the frequency of nursing and related behaviour in several families of *L. arcticus* in the Queen Elizabeth Islands. In the High Arctic 24-hour daylight occurs throughout the summer, and changes in the intensity of illumination throughout the daily cycle are greatly reduced compared to the pronounced day-and-night cycle experienced by more southerly species.

METHODS

Observations were conducted at the National Museum of Natural Sciences High Arctic Research Station at Polar Bear Pass, Bathurst Island (75°43'N, 98°25'W), in June and July 1986, with incidental observations in 1968, and at Sverdrup Pass, Ellesmere Island (79°08'N, 79°45'W) in July and August 1986 and 1987. Additional data were collected by R. Burton at Borup Fiord, Ellesmere Island (80°52'N, 81°53'W) in June-August 1988.

Observations at Polar Bear Pass in 1986 were made from an enclosed observation tower, 3-4 m above the ground. At Sverdrup Pass and Borup Fiord, the observer sat quietly in the open or partially hidden behind boulders at least 10 m from the nursing site. In all cases, 7x35 binoculars and/or a Bushnel spotting scope were used. Nursing behaviour was documented using super 8 mm, 16 mm and 35 mm photography.

The mother of four arctic hare leverets found at Polar Bear Pass on 28 June 1986 marked herself by brushing against some wet paint, making her identifiable. The young were approximately two days old when first observed and were followed until 11 July 1986. A total of 16 nursing sessions were observed. The young were not marked.

A lactating hare was live-trapped at Sverdrup Pass on 17 July 1986. She was ear-tagged with a small green "Allflex" ear-tag, marked with picric acid stain for recognition at a distance and released. On 26 July she was followed until she nursed five young, which were estimated to be approximately five weeks old. This family was observed until 6 September, and data on 24 nursing bouts were recorded. Young hares were not ear-tagged until early September.

In 1987, hares 2-3 weeks old were followed at Sverdrup Pass until they nursed on 14 July. Subsequently, the three leverets were marked with picric acid stain. The female was not marked. Forty nursing bouts were observed until the young were weaned on 16 August.

At Borup Fiord in 1988, a litter of eight leverets was observed intermittently from 26 June to 23 July. Sixteen nursing sessions were observed.

OBSERVATIONS

Birth Sites

On 24 June 1986 one of two hares which frequented the Research Station area of Polar Bear Pass appeared to be pregnant. Attempts to determine visually whether her mammae were enlarged proved unsuccessful because the belly fur was long and thick. She spent much time resting and seemed reluctant to get up when approached.

Four young arctic hares, estimated to be two days old, were discovered in the early afternoon of 28 June. All were within several metres of each other, but no two were together. Two other very young hares were found dead on 29 June, 1986. They were in an unlined, shallow depression, about 0.3 m in diameter, in trampled moss. This nest resembled that described by Walkinshaw (1947).

Nursing-Sites

The young hares observed in 1986 initially gathered for nursing at the presumed birth site or nest. It was situated on a low ridge on the north side of the pass and approximately 55 m above its floor (80 m asl). In the vicinity of the nursing area the flattish ridge top was about 175 m wide. The surface of this raised-beach (Blake 1974) consisted of fine, silt and limestone gravel. Some rocks, protruding no more than 20 cm above the surface, were scattered about the area (none was present in the immediate vicinity of the nest) and provided little cover - particularly for adult hares. The research station was only 20 m from the nursing site. Both adult and young hares sometimes used the buildings, fuel barrels, boxes and glow cones along the landing strip for shelter.

The nursing area on the ridge top was moderately vegetated (approximately 50% ground cover) with plants characteristic of the upland community (Sheard and Geale 1983).

Salix arctica, Saxifraga oppositifolia and *Papaver radicatum* were the predominant vascular plant species. Other common species included: *Dryas integrifolia, Ranunculus* sp., *Oxyria digyna, Cerastium alpinum, Melandrium affine, Draba* sp., *Saxifraga caespitosa, S. cernua, S. flagellaris,* other saxifrage species, grasses including *Alopecurus alpinus, Poa abbreviata, Puccinellia* sp. and *Festuca* sp., as well as various mosses and lichens, providing abundant forage for hares. On the valley floor, about 200 m to the south, virtually 100% of the ground was covered by vegetation. Wet meadows on poorly drained soil surrounding many tundra ponds were lush with sedges and grasses. Hares rarely visited this marsh.

At Sverdrup Pass the nursing site used by a hare family in 1986 was about 1 km north of the main pass, approximately 300 m asl and about 150 m above the floor of the pass. The site was on an exposed, gentle south-facing slope. The substrate consisted was composed of coarse, sharp sandstone, dolomite and limestone gravel. Boulder-strewn areas with granitic erratics and deep ravines were nearby. The site was very sparsely vegetated (<1% ground cover). Species present included: *Saxifraga oppositifolia, S. tricuspidata, S. caespitosa, Dryas integrifolia, Draba corumbosa, Woodsia* sp., *Cerastium* sp., *Salix arctica* and various lichens. Well vegetated, wet meadows (in which adult hares frequently fed) occurred 300 m downslope. The nursing site was seldom visited by hares other than the nursing family.

The 1987 nursing site was approximately 3.5 km southeast of the 1986 site, on a small plateau some 365 m asl and about 215 m above the valley floor. The substrate consisted of predominantly granitic and gneissic rock, and the area was boulder-strewn and sparsely vegetated. This spot was more heavily vegetated than the 1986 site, with approximately 10% cover. Plants were similar but also included: *Cassiope tetragona, Papaver radicatum, Carex nardina* and other unidentified grasses. It was located less than 1 km from the main valley of Sverdrup Pass. Visibility from the nursing site was largely unobstructed for approximately 50 m in most directions. Potential predator-escape terrain was available in steep ravines and moraines bordering the site. Several well vegetated areas and a small glacial meltwater stream and pond were within 70 m. Throughout the summer, the nursing female was the only adult hare seen near nursing site.

The nursing site at Borup Fiord lay among boulders in a gully opening onto a scree fan that spread down the valleyside. It was 213 m asl and 181 m above the large river in the valley.

Congregation of Young Hares

During the first few days, the newborn hares at Polar Bear Pass (1986) stayed within 4 m of the nest, spending most their time sitting still. After two weeks, they spent the non-nursing period at least several hundred metres from the nursing location.

TABLE 1: TIME AT WHICH YOUNG HARES BEGAN CONGREGATING[1] PRIOR TO NURSING.

AGE (weeks)	CONGREGATION OF LEVERETS (weekly mean in minutes)		
	PBP-1986	SP-1986	SP-1987
1	-----	-----	-----
2	52	-----	-----
3	-----	-----	33 (N=8)
4	-----	-----	40 (N=9)
5	-----	59 (N=5)	54 (N=9)
6	-----	57 (N=7)	59 (N=6)
7	-----	52 (N=4)	48 (N=2)

[1] Arrival of first young.
PBP = Polar Bear Pass.
SP = Sverdrup Pass.
N = Number in sample.

Because the young did not stray far from the nest during the first few days of life, it was difficult to determine when they began moving towards the nest in preparation for suckling. During their second week they dispersed ever farther and began making their way towards the nest between 20 and 85 minutes (mean: 52 minutes, N=6) before nursing (Table 1). At Sverdrup Pass during 1986, when young hares were five weeks of age or older, they appeared in the nursing area shortly before nursing. We do not know how far they ranged between nursing bouts. Usually they began congregating about an hour prior to nursing (mean: 56 minutes, range: 32-89 minutes, N=16). In 1987, young hares 3-4 weeks old usually arrived 30-40 minutes (range: 10-71 minutes, N=17) before the female.

This increased to 50-60 minutes (range: 28-90 minutes, N=17) during the fifth and sixth weeks, and remained so until weaning.

Very young leverets usually arrived at or near the nursing spot individually from different directions and at slightly different times. As they matured, two occasionally arrived together, having met before they reached the nursing spot. Once at Sverdrup Pass in 1986, all hares 5-6 weeks old arrived in the nursing area together. In 1987, when the young were perhaps less than 5 weeks old, they arrived and departed from the nursing site separately. The young hares from all three families arrived generally using their own regular routes. As they grew older these routes varied more.

From the beginning of observations at Polar Bear Pass in 1986, the leverets sat in a tight cluster after they had congregated, grooming themselves or nuzzling each other - sometimes apparently attempting to suckle. From five days onward they groomed each other too. As they grew older they spent more time moving about and feeding on vegetation while waiting to be nursed.

Whether the young at Sverdrup Pass (1986, 1987) met at the waiting spot or near it, they frequently ran to each other on first noticing a sibling and "greeted" each other by nuzzling. If several young were involved, the greeting was often followed by the whole group leisurely hopping, single file, in a partial circle. This would last only a few seconds but could be repeated with the arrival of each sibling.

The young hares usually congregated in the open, but on very windy days they tended to wait in the lee of boulders. While waiting for the female to arrive, they sat, backs to the wind, grooming themselves or their siblings, or they hopped about, fed or rested. In several cases they reingested feces. As the nursing time drew near, they would spend increasingly more time sitting close together or in a tight cluster, sometimes touching. Usually they watched for the arrival of the female.

Arrival of Female

Each female hare consistently approached her nursing location from the same direction, and frequently used the same path for the last 100 m or so of the approach. This was not always the shortest distance to the nursing site.

On 28 June 1968 at Polar Bear Pass, a female was observed suckling five very young hares (Hampson 1968). From concealment less than 5 m away, an observer heard her give a short series of low growls as she approached, before the previously motionless young ran to her and began nursing. No vocalization was heard in other circumstances.

At Polar Bear Pass in 1986, the female often spent some time feeding and/or resting several hundred metres from the nest. She made her final approach with a few short pauses, and then dashed directly to the nest where her young waited. When the leverets were older and more active, they ran toward her as she approached. Nursing usually took place immediately at the meeting point. At first the young moved less than 1 m to their mother, but this distance increased gradually. In addition, the female began stopping before the young reached her. So both the spot where the young congregated and the nursing spot gradually shifted away from the nest in the direction of the expected approach of the female. When the young were two weeks old, they congregated about 70 m to the west of the nest and nursed approximately 5 m beyond that.

At Sverdrup Pass, nests were not identified. There in 1986, the female approached the nursing area using one of two routes. She often made a brief stop about 100 m from where the young congregated. The female spent from 1-17 minutes sitting still, grooming and/or feeding a little. She ran the last 90 m or so, either directly or pausing for only a few seconds, and stopped 10-12 m from the young. In this area, too, congregating and nursing spots shifted gradually toward the female's approach route.

In 1987, the doe's behaviour was like that observed in 1986. She consistently approached the nursing site along two routes, with a third route used infrequently. In 1987 the nursing spot shifted approximately 100 m during the five weeks of observations (from the time the young were approximately three weeks old to weaning).

Nursing

When a female arrived at the nursing area, the young hares suckled immediately. The nursing female typically sat upright, with ears erect, eyes open, hind feet in a wide "V" under her haunches, front legs fully extended and front feet rather far apart on the ground.

When the female approached, older leverets (Sverdrup Pass 1986, 1987) she often stopped 10-12 m from them and waited a few seconds in the nursing position until the young reached her. During this time she often laid her ears back against her head and kept her eyes partly closed. The young immediately ran to her, sometimes almost bowling her over. As the young nursed, the female raised her ears and opened her eyes.

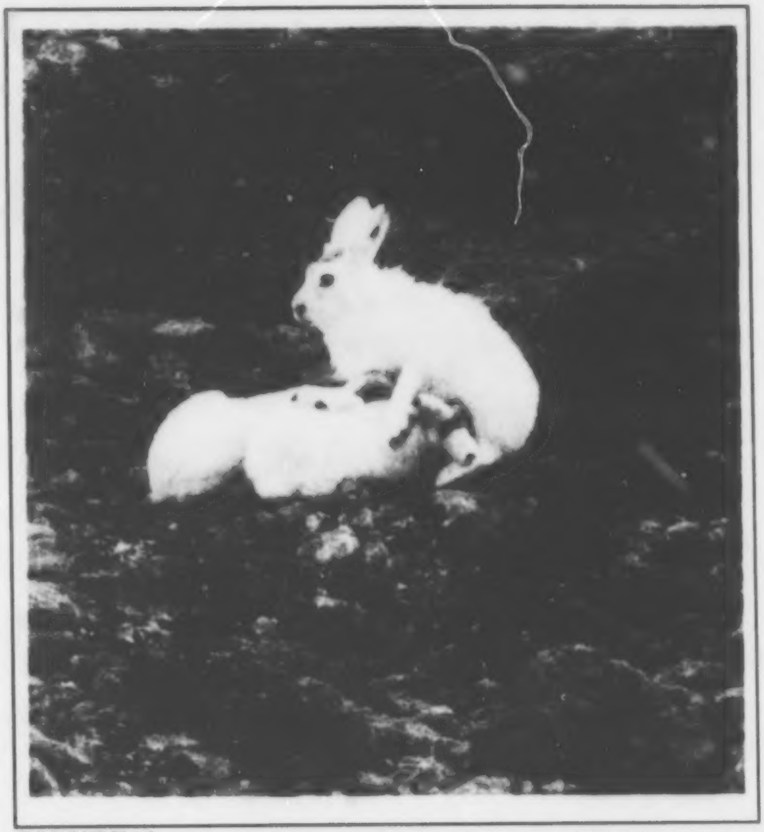


FIGURE 1: Ear-tagged female arctic hare nursing two eight-week-old leverets at Sverdrup Pass, Ellesmere Island, 19 August 1986. Photograph by David R. Gray, NMNS.

After an initial period of intense suckling, one or more leverets would stop (probably when the teat from which it was suckling became dry) and move around rapidly, burrowing between its siblings or climbing on their backs in an attempt to reach another nipple. During each nursing bout, such activity increased with time, probably as milk became scarce. Activity also increased with the age of the leverets. Hares five weeks old and older (Sverdrup Pass 1986, 1987) pushed and shoved a great deal, making it difficult for the mother to stay still. She sometimes could not keep both front feet on the ground and would temporarily rest one front paw on the back of the young (Figure 1).

When the leverets were very young, (Polar Bear Pass 1986), the female frequently licked and/or nosed them on the back or head while they were nursing. Urine licking, as described in *L. europaeus* (Broekhuizen and Maaskamp 1980) was not seen. As the leverets grew older, grooming of the young by the mother became less frequent. By the time the young were five weeks old (Sverdrup Pass 1986), the female still briefly lowered her head but without making contact. This remnant of the grooming movement was performed less frequently until, during the sixth week and later, the female consistently lowered her head only once a few seconds before terminating each nursing bout.

Duration of Nursing Bouts

The duration of nursing bouts at Polar Bear Pass in 1986 varied from approximately 10 seconds to 6.5 minutes (N=15). These extremes occurred in cases which could not be considered normal. In the 10-second bout, which occurred on 5 July, only one leveret was involved; the others failed to appear. This youngster was very sluggish. So were its siblings when they were found later that day. One was found dead the following day, but the remaining three leverets behaved almost normally when they congregated for the next nursing.

On 10 and 11 July, all of the young hares nursed, but not together (see Frequency of Nursing, below). This resulted in a combined nursing period for each bout of approximately 6.5 and 6.0 minutes, respectively, while all other bouts at that age lasted for 2.5-3.0 min.

If the above-mentioned cases are excluded from calculations, the young hares at Polar Bear Pass nursed for an average of 3 minutes (range: 2.5-4.0 minutes, N=11). Table 2 shows that the duration of nursing-bouts decreased from 3.5 minutes (N=4) in the first week of life to 2.8 minutes (N=7) in the second week. In 1987 the duration of nursing for leverets 2-3 weeks old averaged about 2.5 minutes, then levelled off in the fifth and sixth week to about 1.5 minutes and remained constant until weaning. In 1986 the duration of nursing bouts of hares 5-7 weeks old remained almost constant at 1.4 minutes until a few days before weaning, when it declined to 1 minute. Young hares 1-5 weeks old at Borup Fiord nursed for an average of 1.8 minutes (range: 1.2-2.1 minutes, N=16).

Frequency of Nursing

At Polar Bear Pass in 1968, very young leverets were observed nursing on 28 June and again on 29 June. The 18 hours 35 minutes between these two nursing bouts probably constituted a nursing interval. In 1986 the female at Polar Bear Pass nursed her young at a mean interval of 19 hours 48 minutes (range: 19 hours 4 minutes to 20 hours 58 minutes, N=15) (Table 3). In 1986, nursing by the young hares during the first two weeks of life was disrupted on several occasions by the appearance of a wolf or the presence of people. One such case occurred on 30 June. The female arrived at the nest at 0205 hours but found no young. She hopped around and fed within 100 m of the nest and returned to it at 0321 hours when only one young hare nursed. The interval between this suckle and

TABLE 2: CHANGE IN DURATION OF NURSING BOUTS WITH AGE.

AGE (weeks)	DURATION OF NURSING BOUTS (weekly mean in minutes)		
	PBP-1986	SP-1986	SP-1987
1	3.5 (N=4)	-----	-----
2	2.8 (N=7)	-----	-----
3	-----	-----	2.5 (N=12)
4	-----	-----	2.5 (N=10)
5	-----	1.4 (N=7)	1.6 (N=9)
6	-----	1.4 (N=8)	1.5 (N=9)
7	-----	1.3 (N=4)	1.6 (N=4)
8	-----	1.0 (N=4)	

PBP = Polar Bear Pass.
SP = Sverdrup Pass.

TABLE 3: NURSING SCHEDULE - POLAR BEAR PASS, 1986.[1]

DATE	TIME OF NURSING	NURSING INTERVAL	NO. OF YOUNG NURSED
June 29	0645		4
30	0205	19 hrs 20 min.[2]	1
	2115	19 hrs 10 min.[2]	4
July 1	1734	20 hrs 19 min.	4
2	1318	19 hrs 44 min.	3
3	0910	19 hrs 52 min.	3
4	0455	19 hrs 45 min.	4
5	0045	19 hrs 50 min.	4
	2047	20 hrs 02 min.	1
6	1551	19 hrs 04 min.	3
7	1147	19 hrs 56 min.	2
8	0732	19 hrs 45 min.	3
9	0318	19 hrs 46 min.	3
	2244	19 hrs 26 min.	3
10	1942	20 hrs 57 min.	2+1
11	1552	20 hrs 10 min.	2+1+(2)

[1] Observations by B.T. Aniśkowicz.
[2] Arrival of female, not time of nursing, was used to calculate interval (see text for details).

( ) Resuckle.

the previous one was 20 hours 36 minutes, but the interval between her first arrival and the previous suckle was 19 hours 20 minutes, very close to the mean. Thus, the female arrived at the predicted time. Moreover, she subsequently returned to the nest 17 hours 54 minutes after the preceding suckle but 19 hours 10 minutes after her first arrival for the preceding nursing-bout - again close to the mean. It was this interval between arrivals of the female (which, in the absence of disturbance, coincides with the nursing interval) that was used for calculating the mean for this family.

At Sverdrup Pass, the mean nursing interval in 1986 was 18 hours 47 minutes (range: 18 hours 30 minutes to 19 hours 12 minutes, N=21) (Table 4). In 1987 it was 18 hours 36 minutes (range: 18 hours 8 minutes to 19 hours 8 minutes, N=37) (Table 5). At Borup Fiord the interval was 18 hours 23 minutes (range: 18 hours 6 minutes to 18 hours 42 minutes, N=13). Variations in these intervals were small, and some were the result of disturbances such as a predator near or in the nursing area. In one case in 1986, the female was delayed by the presence of other adult hares that tried to accompany her despite her apparent efforts to leave them behind. She spent approximately 20 minutes running about on a high, boulder-strewn plateau until she left the two pursuing hares behind. Then she headed directly to the nursing site.

Missed Suckles

The young usually nursed together. If a leveret arrived late, it almost invariably missed the suckle. This occurred occasionally in all three families observed. Three of the four young at Polar Bear Pass (1968) missed a nursing session when 4 days old. One or several young missed a suckle in four other instances during the first two weeks of life. In 1986 at Sverdrup Pass, a single leveret missed a nursing bout in two instances, one during the fifth week of life and the other during the sixth week. Three other instances of late arrival which resulted in missed nursing occurred in 1987, when the young were 2-4 weeks old.

Even leverets 4 days old did not appear to suffer from missing a nursing session. At that age, and perhaps even earlier, they were eating some fresh vegetation. By the time they were 2 weeks old they ate dry grasses too. As they grew older they spent more time foraging and were observed feeding on dried flower and seed heads, as well as on fresh flowers of: *Dryas integrifolia*, *Papaver radicatum*, *Arenaria* sp., *Oxyria digyna*, *Saxifraga*

TABLE 4: NURSING SCHEDULE - SVERDRUP PASS, 1986[1]

DATE	TIME OF NURSING	NURSING INTERVAL	NO. OF YOUNG NURSED
July 26	1529		5
27	1000[2]	18 hrs 31 min.[2]	-
28	-	-------	-
	2339	-------	4
29	1828	18 hrs 49 min.	3
30	1323	18 hrs 55 min.	4
31	0819	18 hrs 56 min.	4
Aug. 1	0331	19 hrs 12 min.	4
	2228	18 hrs 57 min.	4
2	1743	19 hrs 15 min.	4
3	1213	18 hrs 30 min.	3
4	----	18 hrs 33 min.[3]	-
5	0149	18 hrs 33 min.[3]	4
	2041	18 hrs 52 min.	4
6	1540	18 hrs 59 min.	3
7	1015	18 hrs 35 min.	3
8	0440	18 hrs 25 min.	3
	2340	19 hrs 00 min.	3
9	1816	18 hrs 36 min.	3
10	1256	18 hrs 40 min.	3
11	0759	19 hrs 03 min.	3
12	0252	18 hrs 53 min.	3
17	1434	-------	2
18	0933	18 hrs 59 min.	2
19	-	-------	-
	2321	-------	2
20	1820	18 hrs 59 min.	2
21	1333	19 hrs 13 min.	2

[1] Observations from 26 July to 12 August by B.T. Aniśkowicz. Subsequent observations by D.R. Gray.

[2] Approximate.

[3] Calculated mean.

TABLE 5: NURSING SCHEDULE - SVERDRUP PASS, 1987.[1]

DATE	TIME OF NURSING	NURSING INTERVAL	NO. OF YOUNG NURSED
July 14	0928	------	3
15	0416	18 hrs 48 min.	3
	2230	18 hrs 14 min.	3
16	1735	19 hrs 05 min.	3
17	1202	18 hrs 27 min.	3
18	0652	18 hrs 50 min.	3
19	0128	18 hrs 36 min.	3
	2011	18 hrs 43 min.	3
20	1446	18 hrs 35 min.	3
21	0926	18 hrs 40 min.	3
22	0400	18 hrs 34 min.	3
	2225	18 hrs 25 min.	3
23	1701	18 hrs 36 min.	3
24	1122	18 hrs 21 min.	3
25	0612	18 hrs 50 min.	3
26	0038	18 hrs 26 min.	3
	1928	18 hrs 50 min.	3
27	1403	18 hrs 35 min.	3
28	0838	18 hrs 35 min.	3
	0243	18 hrs 05 min.	3
29	2129	18 hrs 46 min.	3
30	1607	18 hrs 38 min.	3
31	1048	18 hrs 41 min.	3
Aug. 1	0530	18 hrs 42 min.	3
2	0009	18 hrs 39 min.	3
	1840	18 hrs 31 min.	3
3	1316	18 hrs 36 min.	3
4	0810	18 hrs 54 min.	3
5	0234	18 hrs 24 min.	3
	2112	18 hrs 38 min.	3
6	1555	18 hrs 43 min.	3
7	1026	18 hrs 31 min.	3
8	0458	18 hrs 32 min.	3
	2315	18 hrs 17 min.	3
9	1753	18 hrs 38 min.	3
10	1250	18 hrs 57 min.	3
11	----	------	-
12	0153	------	3
	2030	18 hrs 37 min.	2
13	1531	19 hrs 01 min.	2
14	----	------	-
15	0435	------	2

[1] Observations by H. Hamilton and C. Downes.

oppositifolia, *Salix arctica* and *Carex nardina*. Leaves and roots of *Salix*, *Dryas*, *Saxifraga* and *Oxyria* were also consumed.

Young that arrived after the group suckle had ended usually had to wait till the next nursing session. However, two females made exceptions. At Polar Bear Pass (1968), the female allowed a leveret 2 weeks old (who arrived 4 minutes after the group suckle had ended) to nurse. The following day, a leveret again missed the group suckle and was allowed to nurse 5 minutes after the regular bout had ended. Then the female allowed two of the young to resuckle - the only recorded instance of such behaviour. In addition, in five instances in 1987 (when the leverets were approximately 3 weeks old), the female allowed a single young to nurse after it missed the group suckle. In three cases in 1987, the second suckle occurred within 4-5 minutes of the initial suckle. In two instances, there was a gap of 9 minutes and the female had started to leave the nursing site when she returned and nursed the late young. In all cases, the late suckle was of comparable duration to the group suckle, demonstrating flexibility, at least during the first four weeks of nursing.

Termination of Nursing Bouts and Dispersal

The female terminated the nursing bout in all cases, except for two in 1987, when a young hare stopped suckling and left before the others had finished. When the female was about to end a nursing bout she got up on all fours while turning. Then she hopped away, leaving the young behind.

When the leverets were very young, the Polar Bear Pass female frequently stopped about 1 m from the nursing spot, groomed her belly in the region of the mammae and then fed - interspersed with hopping, resting and/or grooming as she gradually moved away from the young. She spent most of the time between nursing bouts alternately feeding and resting several hundred metres from the nest. She disappeared only when a wolf came on 29 June and on several subsequent days, and stayed away for up to 13 hours. By the time the young were 10 days old, the female remained in the nursing area for about 2 hours after each nursing bout. She continued to do this fairly regularly until observations ended when the young were approximately 2 weeks old. When observations began at Sverdrup Pass in 1986, the female nursing young 5 weeks old left the nursing site (and usually the nursing area) immediately after nursing ended.

All three females usually departed along one of several routes they used for approaching their respective nursing sites. However, for a given nursing session a female often would arrive by one route and leave by another.

At first, the leverets at Polar Bear Pass remained in the nest for up to a few minutes before scattering several metres in different directions, or they dispersed immediately after nursing had ended. When about a week old, some of the leverets began following the female for a short time. As one of the leverets came close to its mother, the adult usually hopped away a short distance. This sequence could be repeated a number of times before the young ceased following the mother. By the time they were 2 weeks old some leverets spent up to 2 minutes following the mother after nursing.

Five-week-old young (Sverdrup Pass 1986, 1987) did not always attempt to follow their mother. Sometimes they stayed together for varying lengths of time, feeding close to each other and/or resting. Eventually, they would disperse individually, or two would leave together.

More often, they ran quickly after the mother, who could readily out-distance them. The female either ran until she was out of sight, or she stopped at some distance to groom, rest or feed. At least one young would often attempt to follow her. If any leverets came close, the mother would get up and hop farther away. She would continue until all the young had dropped out. Even when the young caught up with their mother, they rarely attempted to resuckle. If they did, the female invariably moved away. The doe usually did not aggressively rebuff the young, but twice in 1987 this was observed. In both cases, the leveret attempted to suckle again after following the female some distance from the nursing area. The female lunged aggressively at it with her forepaws, although not coming into direct contact. The leveret responded by racing wildly in many directions within a few metres and jumping up. This occurred for several seconds before it abruptly stopped and the young fed quietly near the female. The doe watched this behaviour and when it was over also began to feed quietly nearby.

Both the time the young spent with the mother and the distance they followed her increased with age. By the sixth week (Sverdrup Pass 1986), the young usually followed the female away from the nursing site (Figure 2). At least one young spent 1 hour 25 minutes feeding in the company of its mother and two other adults. In 1987 the young were observed to spend up to 1 hour 15 minutes with the female after nursing.

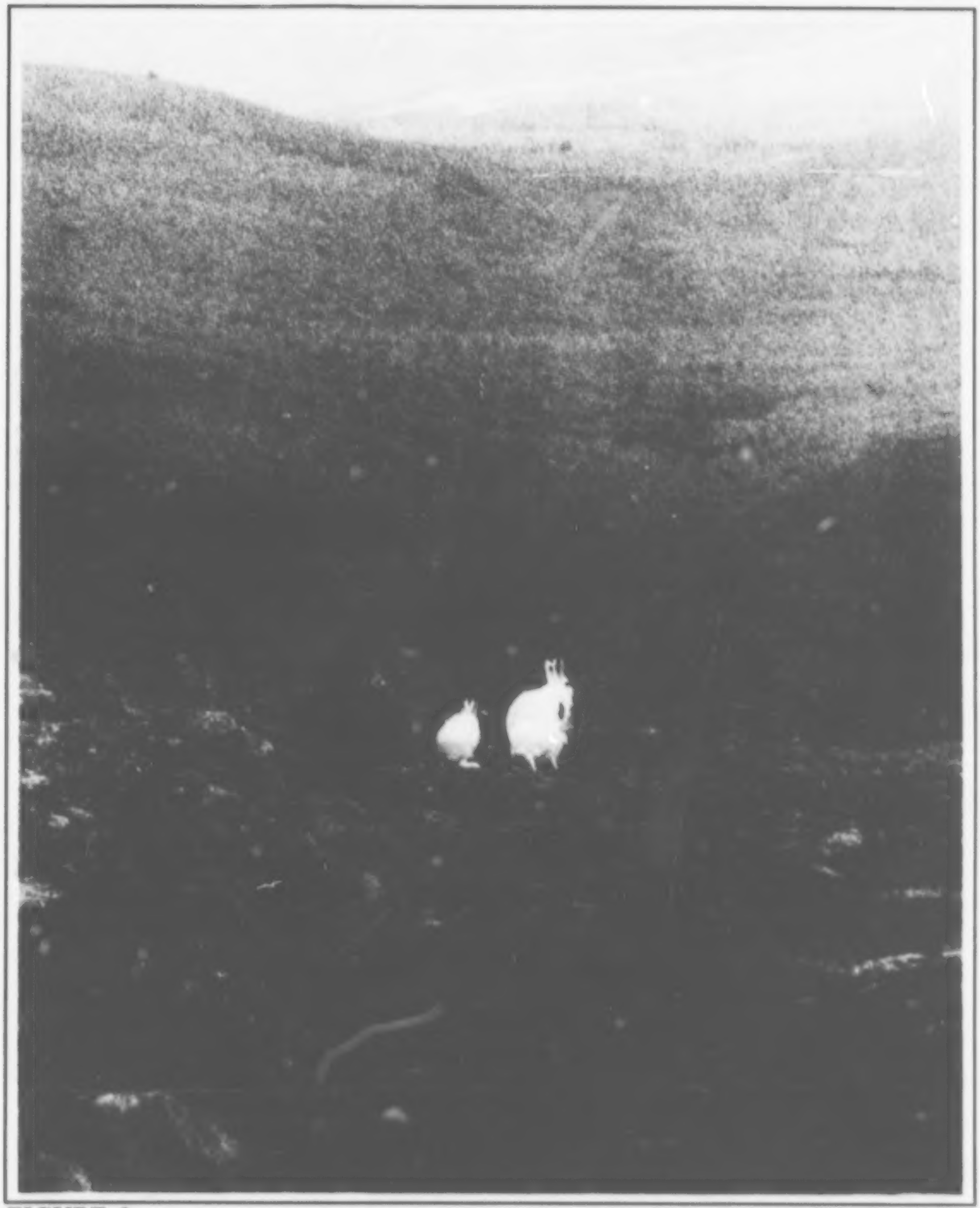


FIGURE 2: Two young hares following their mother as she leaves the nursing site at Sverdrup Pass, 18 August 1986. Photograph by David R. Gray, NMNS.

Whenever leverets from all three families left the nursing area without following the mother, they tended to disperse in different directions along regularly used individual routes. Patterns of route use began to emerge when leverets were in their second week at Polar Bear Pass, but became most evident in older leverets - especially the individually marked ones observed at Sverdrup Pass in 1987. Variations in routes increased with age. In 1987 two of the leverets tended to spend more time together between nursing, and on at least one occasion the whole interval between suckling was spent together.

The dispersal distance also increased as the young hares matured. In 1987, young about 6 weeks old were seen foraging up to 1 km from the nursing site.

Duration of Nursing Period

Weaning of young hares took place in mid- to late-August. Both litters at Sverdrup Pass nursed for about 8 to 9 weeks. On 22 August 1986 and on 16 August 1987, the female did not appear at the nursing site, though in both cases the female was observed in the usual feeding areas. In 1986 both young hares stayed at the site in the absence of the female for 10 hours before leaving. One appeared at the site at the appropriate time the following day and then stopped coming.

On 15 August 1987, two young were at the nursing site when an arctic fox came into the area just before the projected arrival of the female. The fox chased the two leverets out of the area along the path on which the female usually arrived. The female did not appear and the suckle did not occur. Approximately 30 minutes later the female was observed feeding several hundred metres from the site. The next day the same two young were present, but the female did not appear. The young did not appear on the following day.

At Borup Fiord in 1988, determination of weaning was complicated by an arctic fox attacking the young. On 22 July a fox killed a leveret after chasing several at the nursing area. The doe suckled three leverets after the attack, as well as on the following day. Three leverets spent 2 hours at the site on 24 July and two appeared at the appropriate time on 25 July, after which none of the hares was seen again, despite extensive searching.

Contact with Adults Apart from the Mother

Contact of leverets in the nursing area with other adult hares was rare. In 1987, other adults were never observed at or near the nursing site. Although several adult hares occasionally approached both nursing sites in 1986, few contacts occurred. One case of leverets apparently attempting to suckle a strange hare was observed at Polar Bear Pass in 1986. At Sverdrup Pass (1986), adult hares apart from the mother were observed at or near the nursing site on several occasions when the young were in their fifth and sixth weeks. Only on 8 August did the young interact with an adult. Approximately 20 minutes before nursing, two young hares were at the nursing site when an adult came out of the canyon entrance frequently used by their mother. Both young ran toward it. The adult hopped a few steps with the young following, then stopped and both young rushed to it. One young hare wedged its head under the adult, which was standing in a horizontal position, and attempted to nurse. The adult lowered its head toward the young hare and appeared to sniff it, then hopped away with the two young following closely. When a third leveret came out of the canyon entrance, its siblings ran to it, crouched as if to suckle, then nuzzled and sniffed it. Subsequently, the same adult approached again and sniffed one of the leverets, which hopped a short distance away. This was repeated several times and several young were involved. After 7 minutes, the adult fed near the young but no longer attempted to sniff them. Three minutes later the adult left. As far as could be determined, the hare was not lactating and may not even have been a female. After it departed, the young continued to wait for their mother.

As the young grew, they followed their mother for increasing distances until they accompanied her to feeding areas used by other hares. Here, the young contacted other adults. In 1986 this was first observed on 5 August, when the young were in their sixth week. In 1987 the first observed contact occurred on 1 August. On 11 August, two young were observed feeding with two adults (one a marked male and one possibly their mother) about 0.5 km from the nursing site. The hares stayed together for 6.5 hours, during which the male several times chased the young for a short distance.

DISCUSSION AND CONCLUSION

Parental behaviour in the arctic hare (*Lepus arcticus*) is similar to that described for the brown hare (*L. europaeus*) (Broekhuizen and Maaskamp 1980) and the showshoe hare (*L. americanus*) (Rongstad and Tester 1971) with one notable exception: *L. arcticus* does not nurse on a 24-hour cycle. Other hare species live at latitudes with distinct day-and-night periods. Studies have shown that in these species nursing is linked with sunset (Broekhuizen and Maaskamp 1980; Rongstad and Tester 1971). At high latitudes in the Queen Elizabeth Islands, 24-hour daylight exists from well before the time hares are born until weaning. Nursing cycles of *L. arcticus* varied between 18 hours 5 minutes and 19 hours 48 minutes, but were remarkably constant for each family. Such cycles are, necessarily, independent of the daily light regime. The few data on delayed nursing suggest that the female follows an internal clock and is not greatly influenced by the time at which she actually nurses her young.

The 18 or 19-hour nursing cycle may be an important survival factor in the short arctic summer because it increases the number of suckles per unit time. For example, over 8 weeks, arctic hare leverets on an 18-hour cycle would be nursed 75 times, whereas the young of species on a 24-hour cycle would be nursed only 56 times. This extra nursing may accelerate growth and maturation.

The shorter nursing cycle also ensures that the time of nursing is more difficult to predict than when young are nursed at a constant time of day. In addition, the brief amount of time the conspicuous adult spends with the young hares, that are initially cryptically coloured, further reduces the chance of predation.

The location of nesting/nursing sites on exposed ridges and slopes away from areas regularly used by other hares helps to ensure that leverets are not approached undetected at the nursing location. It may serve to minimize leveret mortality, since predators tend to visit areas where prospective prey is abundant. It also results in minimal contact of young hares with adults apart from their mother. Limited observations indicate, however, that young hares at the nursing site will attempt to suckle strange adults, and adults are not aggressive towards strange young.

Young hares that miss a nursing bout are not usually suckled until the next nursing session. Although resuckling is highly unusual, it can occur.

Female brown (*Lepus europaeus*), snowshoe (*L. americanus*), and mountain (*L. timidus scoticus*) hares nurse their final litters of a season (when not pregnant) for 6-8 weeks, although they usually wean earlier litters at 3-4 weeks (Broekhuizen and Maaskamp 1980; Flux 1970; Rongstad and Tester 1971; Severaid 1942 (in Rongstad and Tester 1971)). The 8-to-9-week nursing-period of the arctic hare (*L. arcticus*) is not unusually long as hares in the study area have only one litter per year.

ACKNOWLEDGEMENTS

This project was carried out under the auspices of the National Museum of Natural Sciences (NMNS). The authors gratefully acknowledge the invaluable logistical support provided by the Polar Continental Shelf Project. Additional logistical support was generously provided by First Air of Ottawa. The authors are grateful to S.D. MacDonald and D.A. Gill (NMNS) for collecting some data from Bathurst Island and to R. Burton (British Joint Services Expedition to Borup Fiord) for collecting additional material from that part of Ellesmere Island. The first author is indebted to S.D. MacDonald for the opportunity to work at Polar Bear Pass, and thanks S.A. Edlund for helpful comments on this paper.

REFERENCES

Begerud, A.T. 1967. The distribution and abundance of arctic hares in Newfoundland. Canadian Field-Naturalist 81(4):242-248.

Blake, W., Jr. 1974. Periglacial features and landscape evolution, central Bathurst Island, District of Franklin. Geological Survey of Canada, Paper 74-1B:235-244.

Bonnyman, S.G. 1975. Behavioural ecology of *Lepus arcticus*. M.Sc. thesis, Carleton University, Ottawa. 35 pp.

Broekhuizen, S., E. Bouman, and W. Went. 1986. Variation in timing of nursing in the brown hare (*Lepus europaeus*) and the European rabbit (*Oryctolagus cuniculus*). Mammal Review 16(3/4):139-144.

Broekhuizen, S. and F. Maaskamp. 1980. Behaviour of does and leverets of the European hare (*Lepus europaeus*) whilst nursing. Journal of Zoology 191:487-501.

Flux, J.E.C. 1970. Life history of the mountain hare (*Lepus timidus scoticus*) in northeast Scotland. Journal of Zoology 161:75-123.

Hampson, C.G. 1968. Notes on the behaviour of arctic hares on Bathurst Island, Summer 1968. National Museum of Natural Sciences. Unpublished report. 43 pp.

Hearn, B.J., B.K. Lloyd and O.J. Rongstad. 1987. Demography and ecology of the arctic hare (*Lepus arcticus*) in southwestern Newfoundland. Canadian Journal of Zoology 65(4):852-861.

Lloyd, B.K. 1981. Population dynamics of hares. In: Proceedings of the World Lagomorph Conference (Guelph, Ontario, 1979). Edited by: K. Myers and C.D. MacInnes. pp. 395-440.

Mercer, W.E., B.J. Hearn and C. Finlay. 1981. Arctic hare populations in insular Newfoundland. In: Proceedings of the World Lagomorph Conference (Guelph Ontario, 1979). Edited by: K. Myers and C.D. MacInnes. pp. 450-468.

Parker, G.R. 1977. Morphology, reproduction, diet, and behavior of the arctic hare (*Lepus arcticus monstrabilis*) on Axel Heiberg Island, Northwest Territories. Canadian Field-Naturalist 91(1):8-18.

Pedersen, A. 1962. Polar animals. Harrap, London. 180 pp.

Rongstad, O.J. and J.R. Tester. 1971. Behavior and maternal relations of young snowshoe hares. Journal of Wildlife Management 35(2):338-346.

Severaid, J.H. 1942. The snowshoe hare; its life history and artificial propagation. Maine Department of Inland Fisheries and Game, Augusta. 95 pp.

Sheard, J.W. and D.W. Geale. 1983. Vegetation studies at Polar Bear Pass, Bathurst Island, N.W.T. I. Classification of plant communities. Canadian Journal of Botany 61:1618-1636.

Walkinshaw, L.H. 1947. Notes on the arctic hare. Journal of Mammology 28(4):353-357.

Illustrated by Brenda Carter

HUMAN PREHISTORY

THE PEOPLING OF THE ARCTIC ISLANDS

Robert McGhee[1]

Abstract: Arctic Canada was the last major region of the habitable world to be occupied by mankind. Early Indian occupants of Canada inhabited the Arctic mainland on a seasonal basis by at least 8,000 years ago, but did not penetrate the Arctic Archipelago. The first people to have developed a year-round Arctic adaptation were Paleo-Eskimos who probably came from Asia about 4,000 years ago, basing their Arctic adaptation on two Asiatic inventions: the bow-and-arrow, and finely tailored skin clothing. For the following 3,000 years, Paleo-Eskimos were the primary occupants of most arctic regions, including all but the northwestern islands of the Arctic Archipelago. The Paleo-Eskimos disappeared from the Arctic Islands about 1,000 years ago an event which is related to the expansion of Neo-Eskimo peoples from Alaska, the ancestors of the present Canadian Inuit. These people had developed an extremely efficient maritime adaptation in the marine mammal-rich waters of the Bering Sea, and this adaptation was transferred to much of the Arctic Islands. The development of the Inuit way of life in Arctic Canada occurred over the past millennium during a period of deteriorating climate, which resulted in an impoverishment of the earlier Inuit economy and culture. This process culminated in the Little Ice Age (1600-1850), which saw the Inuit abandon the High Arctic islands.

Résumé: Le Canada arctique est la dernière grande région habitable du monde à être peuplée par l'homme. Il y a au moins 8 000 ans, les Indiens du Canada en occupaient la partie continentale de façon saisonnière, mais ils ne pénétrèrent pas dans l'archipel arctique. Les premiers hommes à vivre en permanence dans l'Arctique furent les Paléo-Esquimaux. Sans doute venus d'Asie voilà environ 4 000 ans, il s'adaptèrent au milieu arctique grâce à deux inventions asiatiques: l'arc et des vêtements de peau finement façonnés. Trois mille ans durant, les Paléo-Esquimaux furent les principaux occupants de la plupart des régions arctiques, y compris tout l'archipel arctique à l'exception des îles du nord-ouest. Ils disparurent des îles il y a environ 1 000 ans, à l'époque de l'expansion des peuples Néo-Esquimaux d'Alaska, ancêtres des présents Inuit du Canada. Les Néo-Esquimaux s'étaient extrêmement bien adaptés à un milieu maritime, celui de la mer de Béring aux eaux riches en mammifères marins, et transportèrent leurs usages dans une grande partie des îles arctiques. Les Inuit du Canada arctique ont développé leur mode de vie au cours du dernier millénaire, période durant laquelle le climat s'est détérioré, entraînant un appauvrissement de l'économie et de la culture antérieures des Inuit. La situation devait continuer de se dégrader jusqu'au Petit âge glaciaire (1600-1850) qui vit les Inuits abandonner les îles de l'Extrême-Arctique.

The Arctic Islands are the homeland of the Inuit. According to Inuit tradition, they have lived in the area since the beginning of the world. The view of the Inuit in popular Canadian culture is somewhat similar. Schoolchildren are taught of the Inuit as the supreme example of the human ability to adapt to their environment; the impression is given that these people have lived in Arctic Canada for countless generations, gradually developing a technology and a way of life which has made them as much at home in the Arctic as are the seals and the caribou. The story of the peopling of the Arctic Islands that comes from archaeological research is quite different; it is a story which is much more complex, and much more human, than that told by either Inuit tradition or popular culture.

Humans are tropical animals. Our ancient ape-like ancestors first stood upright, developed large brains, and learned how to use sticks and stones as tools in the savannahs of the equatorial belt. It is not surprising that the Arctic tundras, polar deserts and icefields

---

[1] Archaeological Survey of Canada, Canadian Museum of Civilization, Ottawa, Ontario, K1A 0M8

were not occupied until mankind had developed fully modern skills, and a technology which allowed survival in northern climates. It was at some time during the last Ice Age, between about 80,000 and 15,000 years ago, that humans developed these capabilities.

Arctic Canada was the last major region of the habitable world to be occupied by people. Although the westernmost part of the area, unglaciated throughout the last Ice Age, saw the first Paleo-Indian immigrants to North America at some time between 12,000 and 20,000 years ago, little trace of their passing has been clearly identified. In the warming climates of the early postglacial period, the descendants of these people began to push northward into the mainland Arctic, leaving traces of Paleo-Indian occupation on the Barren Grounds west of Hudson Bay, and on coastal Labrador, as early as [illegible] years ago.

By this time, most of the Arctic was as habitable as it is today. For the following 4,000 years, however, the Arctic coast and islands remained unoccupied. The Indian groups which inhabited the mainland Barren Grounds appear to have done so on a seasonal basis, much as did the Chipewyan of the Historic period. In the summer they followed the caribou north into the tundra, and in the autumn they retreated to treeline, where the forests provided fuel and shelter from the winter. No group had yet learned how to survive the entire year north of treeline. When such people did appear, it seems likely that they came from Asia, and they based their Arctic adaptation on two Asiatic inventions which were not known previously in the New World: the bow-and-arrow, and finely-tailored skin clothing of an Old World pattern.

The first immigrants were a people who are known to archaeologists as Paleo-Eskimos ("Old Eskimos"), as distinct from the Neo-Eskimo ("New Eskimo") ancestors of the Canadian Inuit. The Paleo-Eskimos are a strangely intriguing people, if only because we know so little about them. They may not have even been Eskimos, in the sense that they may not have spoken a language of the Eskimo family, although they probably spoke a related language; and in physical type were of the same northern Asiatic stock. The Paleo-Eskimos were the first to occupy the islands of the Canadian Arctic Archipelago. They appear suddenly in the archaeological record across Arctic North America, from Alaska to Greenland, approximately 4,000 years ago. Their technology hints at Siberian origins. The tools which they chipped from flint are very distinctive, and resemble those which have been excavated by Soviet archaeologists from 5,000 year old Neolithic sites in eastern Siberia. Their Asiatic origin is also reflected in the remains of their tents, as found archaeologically

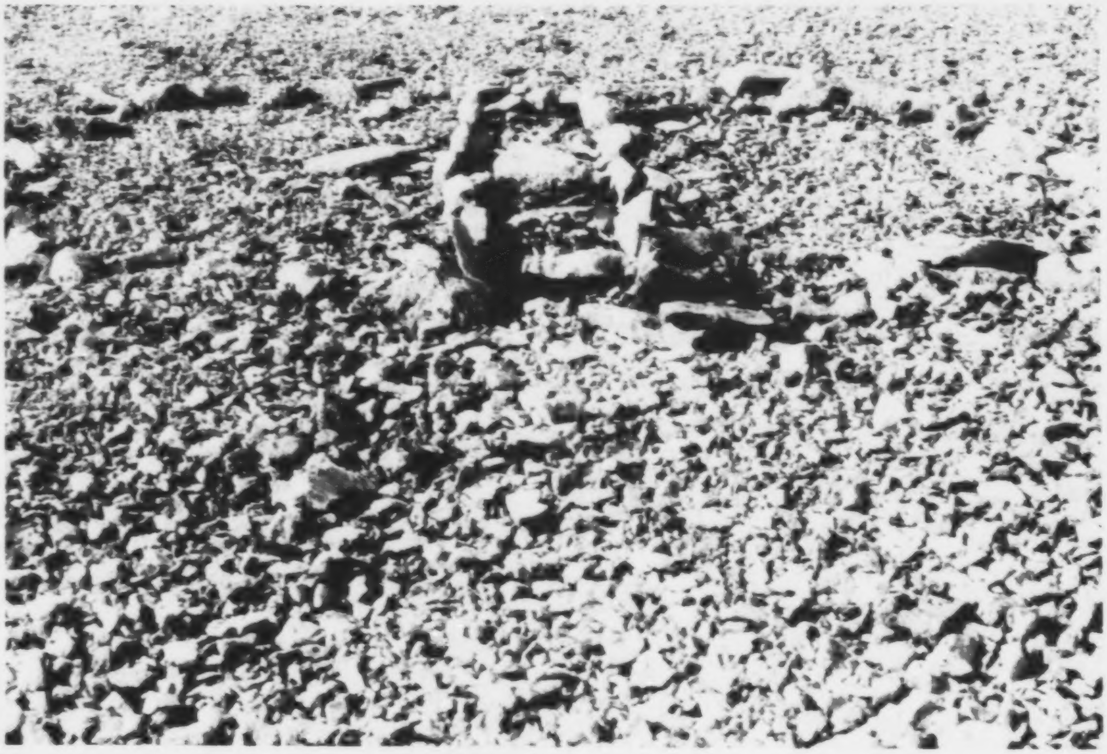


FIGURE 1: Remains of an early Paleo-Eskimo tent with central hearth and midpassage structure. Porden Point, Devon Island.

on Arctic beaches. These so-called midpassage structures are marked by a central box-hearth built of stone slabs, with two sides extended to form a central work-area separating two living or sleeping areas on either side (Figure 1). This is a characteristic northern Asiatic form, similar to the traditional Sammi (Lapp) house of northern Europe, and of the Samoyedic peoples of Siberia. The Paleo-Eskimos brought with them from Siberia an adaptation which allowed people to live on all but the most remote northwestern Arctic Islands. For the following 3,000 years, their descendants were the primary occupants of most arctic regions, occasionally expanding southward as far as Lake Athabaska in the west, and the island of Newfoundland in the east.

The early Paleo-Eskimos seem to have led lives of terrifying simplicity and endurance, lacking many of the technological items that allowed later Inuit occupants of the Arctic to live in relative comfort. Although the Arctic climate of 4,000 years ago was slightly warmer than at present, it was still a treeless country where winter temperatures regularly fell below -30°C for weeks on end, through the darkness of the winter night. Yet the Paleo-Eskimos seem to have lived throughout the year in skin-covered tents, heated only by occasional small fires of animal fat, bones, chips of driftwood and willow twigs. There is no evidence that they possessed boats or dog-hauled sleds, which must have limited not only their hunting capabilities but their ability to move in order to escape starvation if local game resources failed. Their main weapons were the bow, and the harpoon with hand-held retrieving line, lacking the harpoon-float equipment which allowed the later Inuit to kill sea mammals larger than seals with relative ease. Settlements seem to have been very small and temporary. Their total population may have consisted of only a few hundred people scattered over several million square kilometres of Arctic landscape. Yet the Paleo-Eskimos managed to survive, although marginal regions such as the High Arctic islands seem to have been largely abandoned after the climatic deterioration which began some 3,500 years ago.

Although the archaeologist may be appalled by the remains of such an apparently meagre way of life, the meagreness does not show in the artifacts that we find around the camps of these Arctic pioneers. Their craftsmen seem to have been interested in more than the functional aspects of these tools: they selected multicoloured stones, chipped them very evenly and symmetrically, often with decorative edge serration, and their extremely small size suggests that great value was placed on the skill necessary to create such miniature pieces (Figure 2). Flintworking is one of our oldest and most difficult crafts, yet few cultures have surpassed the early Paleo-Eskimos in their skill in handling this intractable material. If we can call this an art form, then its usefulness and portability would seem to have been perfectly suited

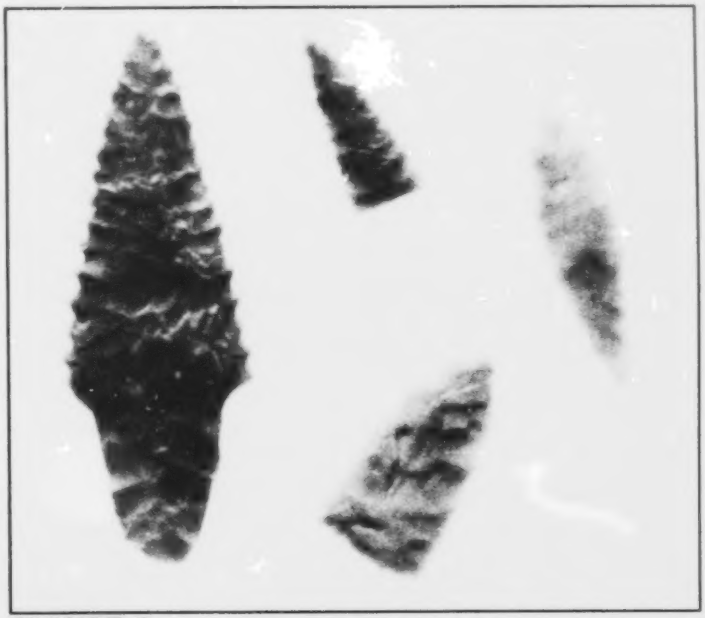


FIGURE 2: Small chipped-stone points for lances, arrows and harpoons. Early Paleo-Eskimo, Port Refuge, Devon Island.

to the lifestyle of these first occupants of Arctic North America. These beautifully-crafted tools are welcome evidence that we are looking at the remains of people who not only survived, but who enjoyed their lives.

Beginning nearly 2,500 years ago, Paleo-Eskimos across Arctic Canada began to develop techniques that must have made their lives more comfortable and secure. Winter houses with stone and turf walls were used in some areas, and dwellings were now heated and lighted by oil lamps carved from soapstone. There is slight evidence that they may have possessed dogs, and perhaps kayaks, which must have greatly increased the efficiency of their hunting. The remains of their settlements are larger and represent more permanent habitations than did those of their ancestors. These later Paleo-Eskimos are known as the Dorset people - named after the Baffin Island community of Cape Dorset where their archaeological remains were first recognized. The Dorset culture dominated Arctic Canada until it suddenly disappeared from most regions about 1000 years ago.

The Dorset culture developed in the eastern Arctic during a period when the climate was rapidly cooling. For an ice-hunting people such as the Paleo-Eskimos, such a change may have provided greater hunting opportunities, a challenge to the usual assumption that colder climates make living conditions more difficult for northern peoples. The Dorset people spread southward as far as Newfoundland, where they were the primary occupants for 1,000 years, and northward to Ellesmere Island and northern Greenland. Wherever they went, they left in the ruins of their camps unique pieces of art: tiny, exquisite sculptures in ivory, antler and wood, representing humans, other animals, and spirits.

These carvings appear to have been made during the 1,500 years that Dorset people occupied Arctic Canada: but during most of this time, only a few scattered examples of such carvings are known. However, during the final two or three centuries of the Dorset period, approximately 1,000 years ago, there was a great explosion of artistic production. This coincides with a major expansion of Dorset occupation to many parts of the Arctic Archipelago which appear to have been abandoned, or very sparsely populated, during the preceding centuries. For a few generations, Dorset people lived from Labrador to northwestern Greenland, and across the Arctic Islands to the shores of Amundsen Gulf. It is these people who produced most of the carvings that make up our collections of Dorset art. It was an artistic tradition rooted in the Paleo-Eskimo past, but which flourished for only a few generations, and was remarkably standardized across the Arctic, apparently through widespread communication networks, and perhaps even through trade in carvings themselves.

The carvings, which appear to have been intimately associated with shamanistic religion, afford us a rare insight into the beliefs of the Dorset people: wooden masks probably used by a shaman in h rituals of curing or hunting magic; sets of carved animal teeth designed to be held in the human mouth in order to give the impression of transformation into an animal; small wooden carvings of people or animals which have been magically "killed" with a slit in the throat or chest (the slit sometimes contains a spike of wood); and the skeletal motif added to many carvings, particularly those of bears, perhaps relating to the importance of the skeleton in shamanic thought.

The meaning and use of other objects is less clear. Portions of caribou antler carved with up to 60 human or human-like faces may be cartoon-like portraits of the members of a local community, representations of a pantheon of spirits, or a shaman's record of his varied spirit-helpers. Pendants in the form of animals may have been used as personal amulets. Other carvings of animals may simply have been playthings, or objects made for the delight of the artist or his audience. Using vague estimates of community size and duration of occupation from a Dorset site that I excavated a few years ago on Bathurst Island in the High Arctic, I have calculated that between approximately 0.1 and 1 carvings were lost or abandoned per person per year at the site. This figure suggests that carvings were produced or acquired with about the same frequency that present-day Canadians acquire wrist-watches or pocket-calculators: somewhere between once a year and once every ten years. It is tempting to guess that these carvings may have had a similar level of significance, or usefulness, to the Dorset people as that which we apply to such personal items. From these carvings we obtain a rare glimpse of the aesthetic and spiritual life of an extinct people, a people whose world was populated with humans and animals whose spirits could be magically controlled by shamans in order to combat illness, bad weather, or poor luck at hunting.

The great florescence of Dorset carvings about 1,000 years ago also marked the approaching end of the Dorset people, and may perhaps be in some way related to the stresses produced by a changing environment and the arrival of newcomers in their lands. So the Dorset Paleo-Eskimos disappeared from most Arctic regions about 1,000 years ago, surviving only in the Ungava Peninsula of northern Quebec and Labrador until perhaps 500 years ago. The disappearance of the Dorset people coincided with, and is almost certainly related to, the expansion into their territory of Neo-Eskimos from Alaska, the ancestors of the present Canadian Inuit. These people were descended either from Alaskan Paleo-Eskimos, or from an earlier group of people who had crossed the Bering Isthmus and established a maritime hunting way of life in southern Alaska. By the final millennium B.C. (about 3,000-2,000 years ago), these people found themselves between, and in at least occasional contact with, two rapidly developing culture areas: to the west, the Bronze and Iron Age peoples of Siberia, and to the south the Indian peoples of the Northwest Coast. Between roughly 2,500 and 1,000 years ago, they developed an extremely efficient maritime adaptation in the marine mammal-rich waters of the Bering Sea, and had evolved most of the technology characteristic of later Eskimo cultures: half-buried (semi-subterranean) winter houses covered with turf and heated by oil-lamps; skin-covered kayaks and larger umiaks capable of pursuing whales or carrying an entire camp; efficient float-harpoon gear, sinew-backed bows; and other hunting and fishing weapons. These people could no longer be classified as belonging to the stone age, since their technology was dependent on small pieces of metal obtained by trade from the civilizations of China or Central Asia.

About 1,000 years ago the Arctic climate became somewhat warmer, in step with that of Europe where the time is characterized as the Mediaeval Warm Period. This warming may have resulted in a decrease in sea ice in Arctic Canada and a consequent extension of the range of the bowhead whale, the 10 to 20 m long animal that was a prime prey of the Eskimos of northern Alaska. These conditions may have encouraged the movement of Alaskan Eskimos eastwards into Arctic Canada. There is a possibility, however, that the warming climate and decreased sea ice merely allowed such a movement, and that the impetus behind the invasion of Arctic Canada was the presence of metal in the eastern Arctic: meteoritic iron from the Cape York meteorite fall in northwestern Greenland. It is interesting that what appear to be the earliest Thule sites known in the eastern Arctic occur in northwestern Greenland and on adjacent Ellesmere Island, and contain quantities of not only meteoritic iron but of smelted metal obtained from the Greenlandic Norse.

Whatever the reason behind the Eskimo expansion eastward, the evidence suggests swift occupation of most Arctic regions, and the archaeological disappearance of the Dorset people. Inuit legends tell of their ancestors killing or driving away a race of people called *tunnit* who were the previous occupants of Arctic Canada. If we can identify the legendary *tunnit* with the archaeologically-known Dorset people, then legend and archaeology appear to support one another: the Paleo-Eskimos were killed or driven to extinction about 1000 years ago, at the hands of the early Inuit invaders.

These whale-hunting immigrants, the ancestors of the Inuit, are known as the people of the Thule culture, named for the community in northern Greenland where their remains were first discovered. The Thule expansion eastward resulted in the wholesale transfer of an Alaskan culture and way of life across the Canadian and Greenlandic Arctic. Permanent winter villages similar to those of their Alaskan ancestors were established, but the houses were built from boulders and whale bones rather than driftwood logs (Figure 3). Adapting their hunting technology to local conditions, they were capable in most regions of maintaining a way of life comparable to that of their Alaskan relatives. By about 800 years ago, this way of life had been established across all but the most remote northwestern Arctic Islands.

The Dorset *tunnit* were not the only people whom the Inuit met in the Arctic Islands. Very soon after they arrived in Arctic Canada, they encountered the Norse who had recently established colonies in southwestern Greenland, and who appear to have made at least occasional visits to northeastern Canada over a period of a several centuries. A few items of European origin are found in most Thule villages: small pieces of smelted iron or copper, fragments of chain mail, boat-nails, and objects such as a portion of a bronze trader's balance found on Ellesmere Island. Visits by the Norse to the Arctic Islands are suggested by an Inuit carving of a person in European clothing, found in a thirteenth century Thule village on Baffin Island. In Greenland, there is growing evidence that the Inuit and the Norse shared the country in apparent peace for at least two centuries.

But despite their apparent success, the Thule Inuit occupation of Arctic Canada was essentially the transposition of a way of life that was adapted to the coasts of the Bering and Beaufort seas, to a region which could only temporarily support such an existence. After the twelfth century, the climate began to deteriorate, sea ice increased in both extent and seasonal duration, and the ranges of large whales must have been considerably restricted. Whale stocks may have been further reduced by European hunting in the North Atlantic, which began on a large scale during the sixteenth century. By the seventeenth century, when Europe entered a period of cold climate called the Little Ice Age, Thule people throughout the Arctic Islands had begun to revert to a way of life similar to that of their

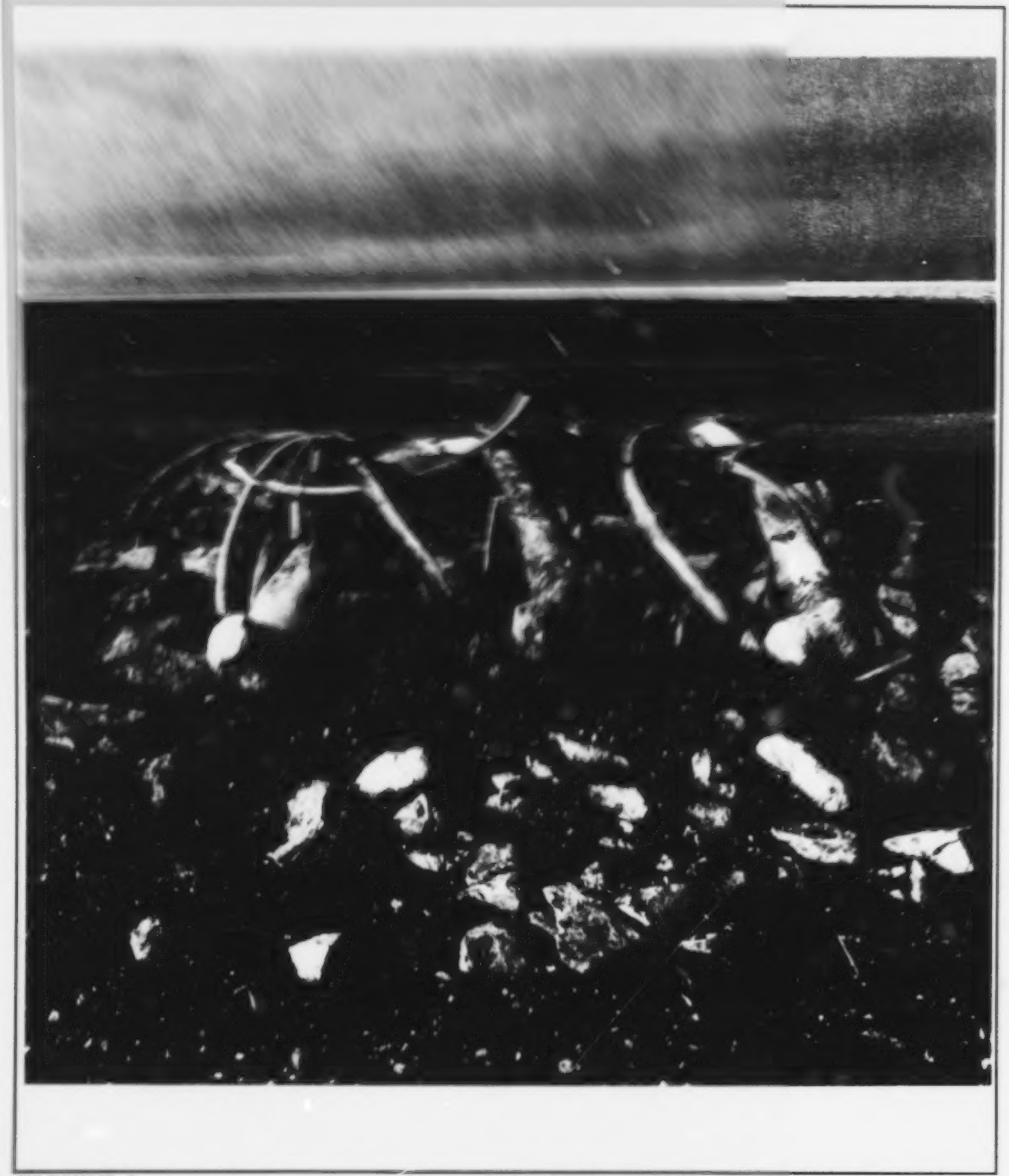


FIGURE 3: Reconstructed Thule winter house with whale mandible roof supports. Brooman Point, Bathurst Island.

Dorset predecessors. Summers were no longer spent hunting whales (Figure 4) and other large sea mammals from boats in open water, but hunting inland caribou, muskoxen or fishes. The lack of summer-stored food made the occupation of large permanent winter villages of whale bone and turf houses impossible, and people began using temporary snow-houses on the sea-ice, from which they could hunt small ringed-seals, the only abundant prey during the arctic winter. Only in the relatively warm and ice-free regions of Greenland, Labrador, and portions of Baffin Island, were people capable of maintaining an essentially Thule way of life until the time of European contact.

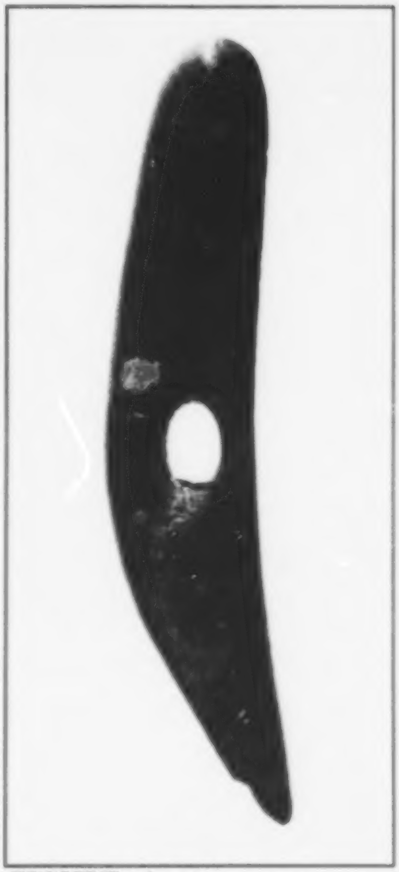


FIGURE 4: **Whaling harpoon head carved from whale bone. Early Thule culture, Porden Point, Devon Island.**

When European explorers began to penetrate the Arctic Islands during the eighteenth and nineteenth centuries, they described a series of Inuit cultures which were so meagre, and so ingenious in their adaptations to the harshest habitable region of the world, that it was generally considered that such ways of life were the result of millennia of adaptation to such a severe environment. What we have learned from archaeology is that this is not true: traditional Canadian Inuit ways of life are the remnants of what, a few centuries ago, was a much richer and more sophisticated culture, and one that adjusted rapidly through a series of make shift adaptations to a deteriorating climate and environment, during the centuries immediately preceding European contact.

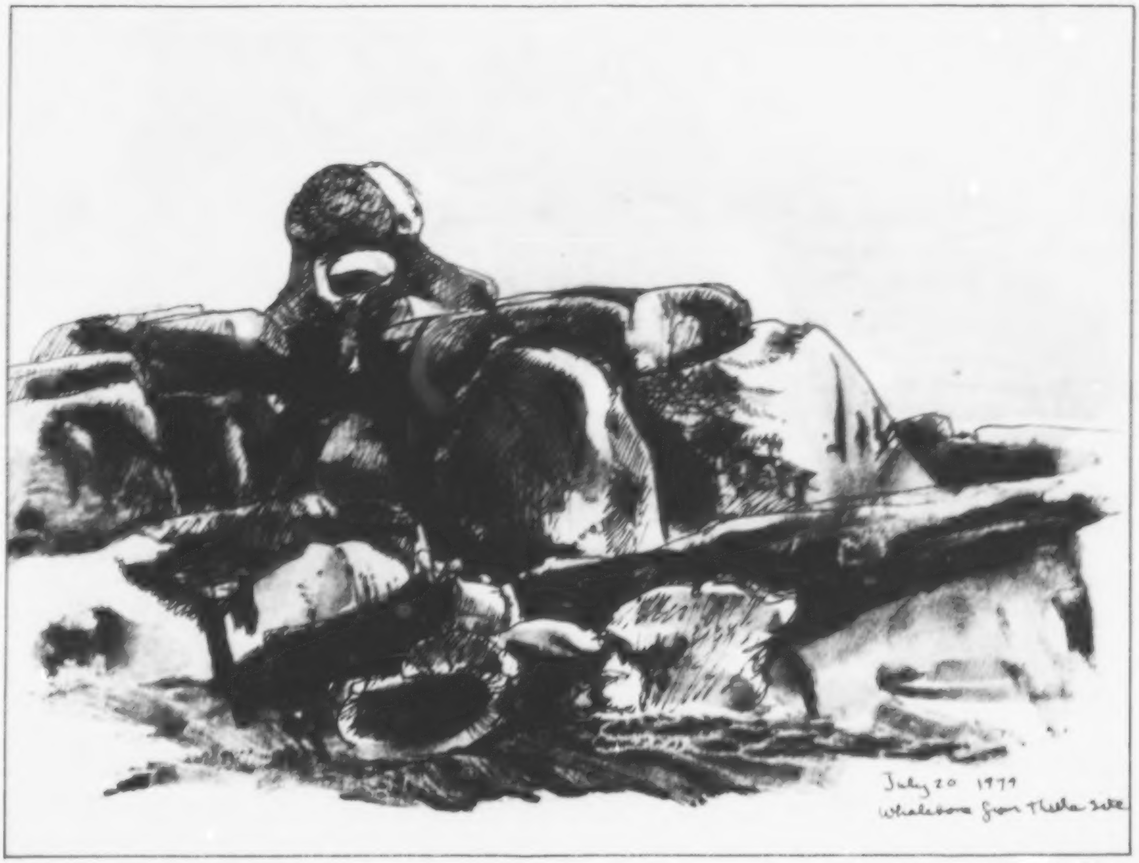
As I mentioned at the beginning of this paper, the development of Inuit culture in Arctic Canada was neither simple nor direct. It is not a story of simple and gradual, animal-like adaptation to a harsh environment. Rather it is a complex story involving population expansions into unused areas, survival or retreat when things went badly, invasions, and learning to live with and profit from strange peoples. It is a story which, although unique, involved processes which were not all that simpler than, or different from, those affecting the histories of most human populations.

REFERENCES

Dumond, D.E. 1977. The Eskimos and Aleuts. Thames and Hudson, London.

Maxwell, M.S. 1986. Eastern Arctic prehistory. Academic Press, Orlando.

McGhee, R. 1978. Canadian Arctic prehistory. Van Nostrand Reinhold. Toronto.



July 20 1979
Whalebone from Thule site

Illustrated by Brenda Carter

THULE PIONEERS IN THE CANADIAN ARCTIC

Charles D. Arnold[1] and Karen McCullough[2]

Abstract: Archaeological investigations on Banks Island in the western Canadian Arctic and on Ellesmere Island in the east have revealed evidence for pioneering groups of Thule Inuit in each of those areas. The Banks Island occupation represents the initial expansion of Thule into the Canadian Arctic, and the sites on Ellesmere Island contain archaeological remains of a later group that migrated eastward from Alaska. These data show the complex nature of processes involved in the prehistoric development of Inuit culture.

Résumé: Des recherches archéologiques sur l'île Banks, dans l'ouest de l'Arctique canadien, et sur l'île Ellesmere dans l'est, ont montré avec certitude la présence de groupes de pionniers inuit de Thulé à ces endroits. L'occupation de l'île Banks représente l'expansion, dans les débuts, de Thulé dans l'Arctique canadien, alors que les sites de l'île Ellesmere renferment des vestiges archéologiques d'un groupe postérieur, migrant de l'Alaska vers l'est. Ces informations illustrent la complexité des processus qui font partie du développement préhistorique de la culture des Inuits.

INTRODUCTION

Geographical shifts were a common fact of life for Inuit in pre-contact times. Nomadic groups of Inuit migrated to follow or to intercept game, to seek out new hunting grounds, to obtain raw materials from distant sources, and for many other reasons. Inuit often moved on foot, but they also possessed a well-developed transportation technology that included dog-drawn sledges and skin-covered boats which allowed them to move whole camps. They also had an open, flexible social system which facilitated the movement of people by accommodating newcomers.

Most of these movements probably took place within a known geographic area, but periodically in the history of the Canadian Arctic there were long-distance migrations of people, which took them into unoccupied or only sparsely occupied territories. In addition to expanding the geographic range of a culture, the process of colonizing new territory also served as an agent for cultural change. This paper summarizes investigations of two pioneering episodes involving the immediate ancestors of the present-day Inuit, whose culture is known archaeologically by the term "Thule". These investigations took place at opposite ends of the Canadian Arctic (Figure 1), and so provide us with a unique perspective on the early movements of the Thule people into their new homeland.

---

[1] Prince of Wales Northern Heritage Centre, Yellowknife, Northwest Territories X1A 2L9
[2] The Arctic Institute of North America, University of Calgary, Calgary, Alberta T2N 1N4

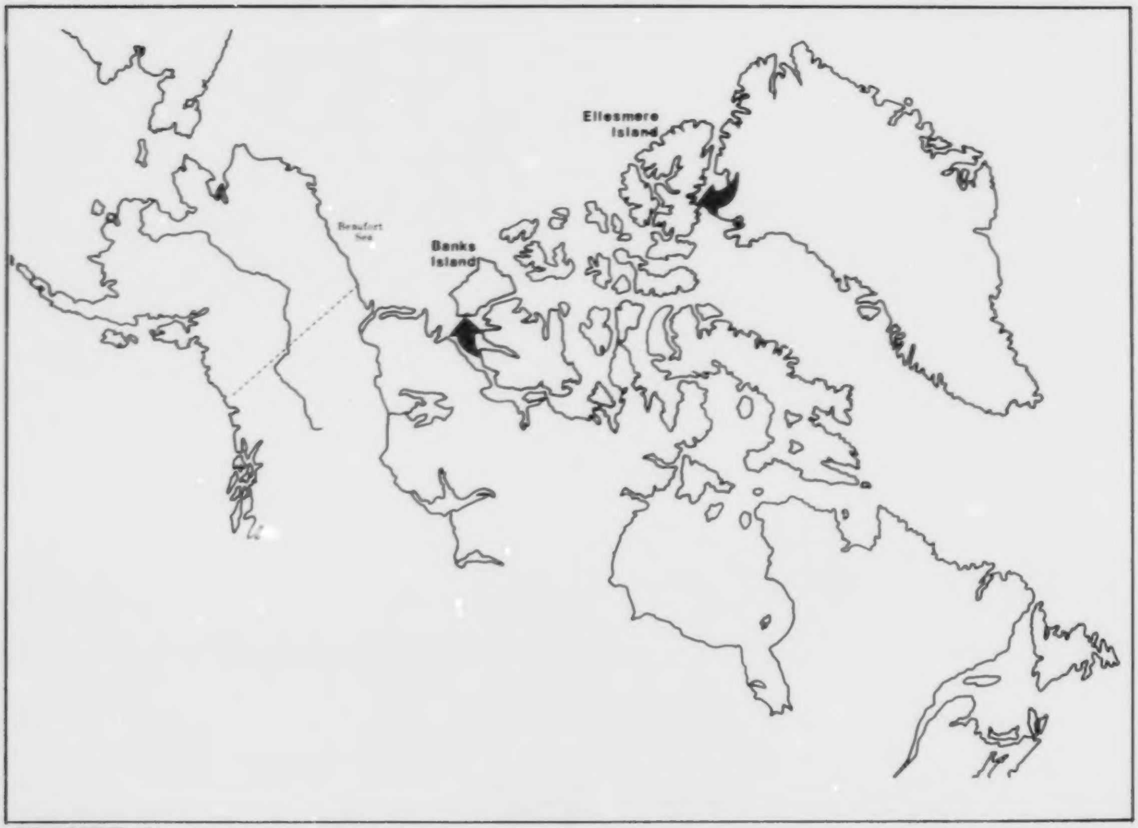


FIGURE 1: The study areas. The Nelson River site is indicated by the arrow pointing to southeastern Banks Island, and the Skraeling Island sites are situated at the tip of the arrow pointing to eastern Ellesmere Island.

EARLY THULE MIGRATIONS

Origin and Expansion of Thule

The Thule people were not the first to live in the far northern parts of Canada. An earlier migration that began about 4,000 years ago saw even more ancient people whom archaeologists call "Paleo-Eskimos", move out of western Alaska into the Canadian Arctic and Greenland, eventually extending along the northeastern coast of North America and into Newfoundland (Figure 2; McGhee, this volume). Within this vast geographic expanse, local Paleo-Eskimo cultures developed and changed as time progressed. Some of the most far-reaching cultural developments took place in the Bering Sea and Bering Strait regions of western Alaska. There, about 2,000 years ago, Paleo-Eskimos devised, or perhaps borrowed, the techniques and technology to hunt large sea mammals from boats. Accompanying this development were shifts in population, settlement and other factors which gave rise to what

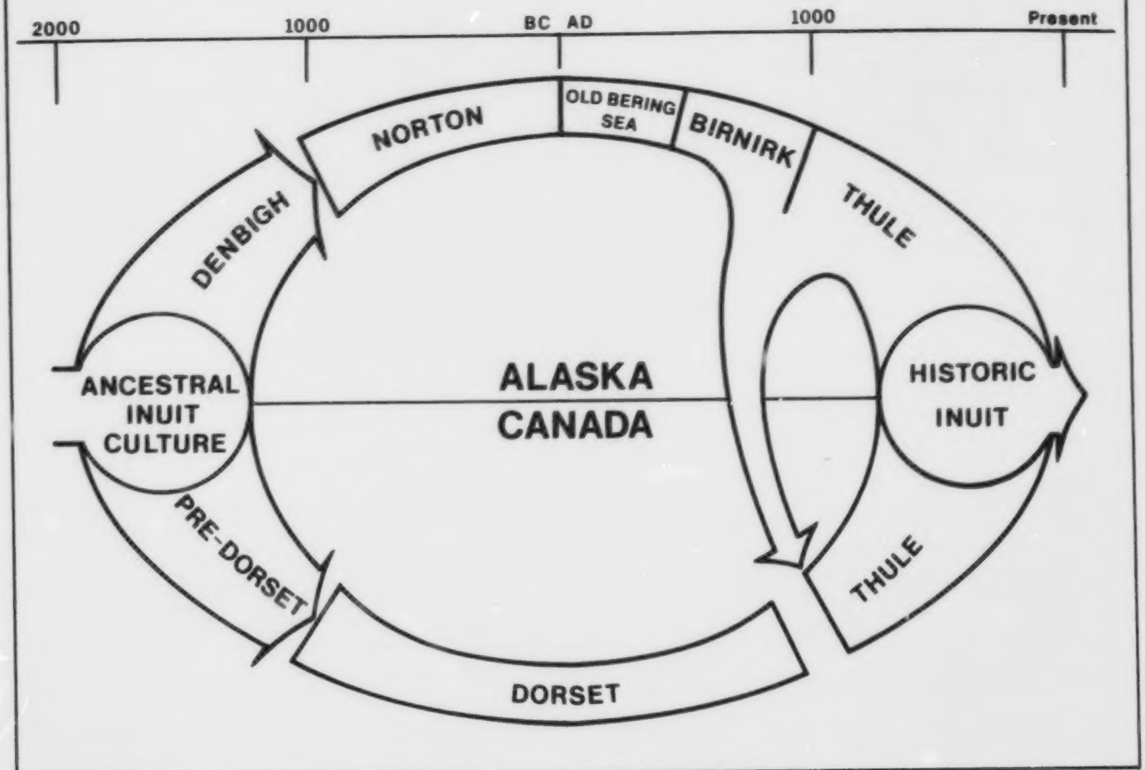

2000
1000
BC AD
1000
Present
NORTON
OLD BERING SEA
BIRNIRK
DENBIGH
THULE
ANCESTRAL INUIT CULTURE
ALASKA
CANADA
HISTORIC INUIT
PRE-DORSET
THULE
DORSET

FIGURE 2: The way of life of the Thule people had its roots in earlier Neo-Eskimo cultures (Old Bering Sea and Birnirk) in Alaska, and in even more ancient Paleo-Eskimo cultures (Denbigh, Norton, Pre-Dorset, and Dorset).

have been termed the "Neo-Eskimo" cultures.

Nearly 1,100 years ago (about 900 AD), the regional expression of Neo-Eskimo culture known as Thule was poised at the western edge of the Canadian Arctic, then only sparsely occupied as the Paleo-Eskimos there had undergone a marked decline in geographic extent and numbers. The immediate ancestor of Thule culture was a phase, or variant, of Neo-Eskimo called Birnirk which had appeared several centuries before in northern Alaska, where people had adapted efficiently to the resources and environment of that area.

Archaeologists who have studied Thule culture have advanced several theories to account for the transition from Birnirk to Thule in northern Alaska, and for the subsequent movement of Thule people into the Canadian Arctic. One of these, which has gained a high degree of popularity, attaches considerable importance to evidence suggesting that those events occurred during a climatic trend underway by 900 AD which saw average temperatures in the Arctic become substantially warmer than those of today.

A climatic shift of this nature would have altered the distribution and availability of marine mammals in several important ways. According to a model developed by Robert McGhee (1969-1970), changes in the availability of bowhead whales were of paramount importance to the appearance of Thule culture. During the Birnirk period in northern Alaska, techniques were devised to hunt whales in spring when they began to move eastward through narrow leads that develop along the southern edge of the pack ice. Before 900 AD, when the climate was like today's, these leads probably were inshore and bowhead whales were easy to spot and chase using umiaks launched in the open water leads. But the actual kill must have been a dangerous affair. The model supposes that the post-900 AD warming would have shifted the position of pack ice northward, so the spring open water leads might have been too far offshore for such hunting to be feasible. In order to continue the whale kill, a shift to a summer hunt in the open water would have been required. The normal summering grounds of bowheads are in the eastern Beaufort Sea. If a shift to open water hunting was made, then those waters would have presented better opportunities for hunting than would the northern coast of Alaska, where whales are found only briefly during spring and fall migrations.

These and other interdependent events may have triggered the development and initial expansion of Thule. Until recently it was difficult to assess this model, since the archaeological trail left by early Thule migrants was sparse, and the meagre evidence controversial. Now, we have clear evidence of pioneering Thule groups from at least two parts of the Canadian Arctic, southern Banks Island and northeastern Ellesmere Island, which can be used to evaluate and perhaps to refine this model.

Nelson River Thule

In 1980 and 1981, Arnold (1986) conducted fieldwork on southern Banks Island, searching for archaeological remains from the early Thule period. There were several good reasons to suppose that such evidence could be found there.

Banks Island is the westernmost of the islands in the Canadian Arctic Archipelago, and as such is the closest to the Alaskan Thule homeland. It is richly vegetated by most arctic standards, and the plant life in turn supports an abundance of wildlife of economic interest to people, including the world's largest concentration of muskoxen. Peary caribou are also common, and multitudes of various species of waterfowl nest in the wet, low-lying parts of the island. Nutrient-rich waters flowing into the Beaufort Sea from the west bring migratory bowhead whales close to the southern shores, and more sedentary ringed and bearded seals are common. Given these biological and geographical factors, it seemed reasonable to expect that Banks Island would have been occupied by the pioneering Thule groups from Alaska.

Fieldwork designed to test this possibility focused near Nelson River on the southeastern coast of the island, in part because it juts out into the Beaufort Sea, and also because excavations at an archaeological site there in the 1950s had hinted at an early Thule presence. Altogether five Thule sites were investigated there during two field seasons. One in particular, the Nelson River site, seems to be from the culture's initial stage. Only one house at the Nelson River site was well preserved, but it yielded an abundance of information about the culture of the early pioneers.

The surface deposits on Banks Island are mainly sedimentary in origin, and geological forces have contributed to redeposition of sands and silts across the landscape. The remains of the Nelson River house, found in a low sand dune, were covered by as much as 1 m of overburden (Figure 3). They were firmly encased in permafrost, resulting in excellent preservation of architectural details, animal bones and artifacts. Excavations revealed the floor and parts of the walls of a substantial dwelling of two rooms, joined by their entrance tunnels (Figure 4).

According to our excavations, evidently the dwelling had been erected over a depression that had been dug into the ground. The main structural elements were posts and beams of driftwood which can be found in places along the shore of this part of the island. Adzed planks were used for the floor and walls, and perhaps for the roof. Next to one of the rooms we found a concentration of scorched rocks and charcoal cemented by seal oil, which we interpreted to have been a kitchen floor. Evidently walls did not enclose the kitchen, so perhaps cooking was done in a tent attached to the dwelling. This would have prevented smoke from driftwood cooking fires from polluting the main structure, and cooking in a tent also would have reduced the hazard of sparks igniting the dry driftwood structure of the house. The main part of the dwelling was covered with an insulating layer of sod blocks, weighted down with stones (Figure 5). Such structures are known to have been used throughout the Arctic as cold-season dwellings.

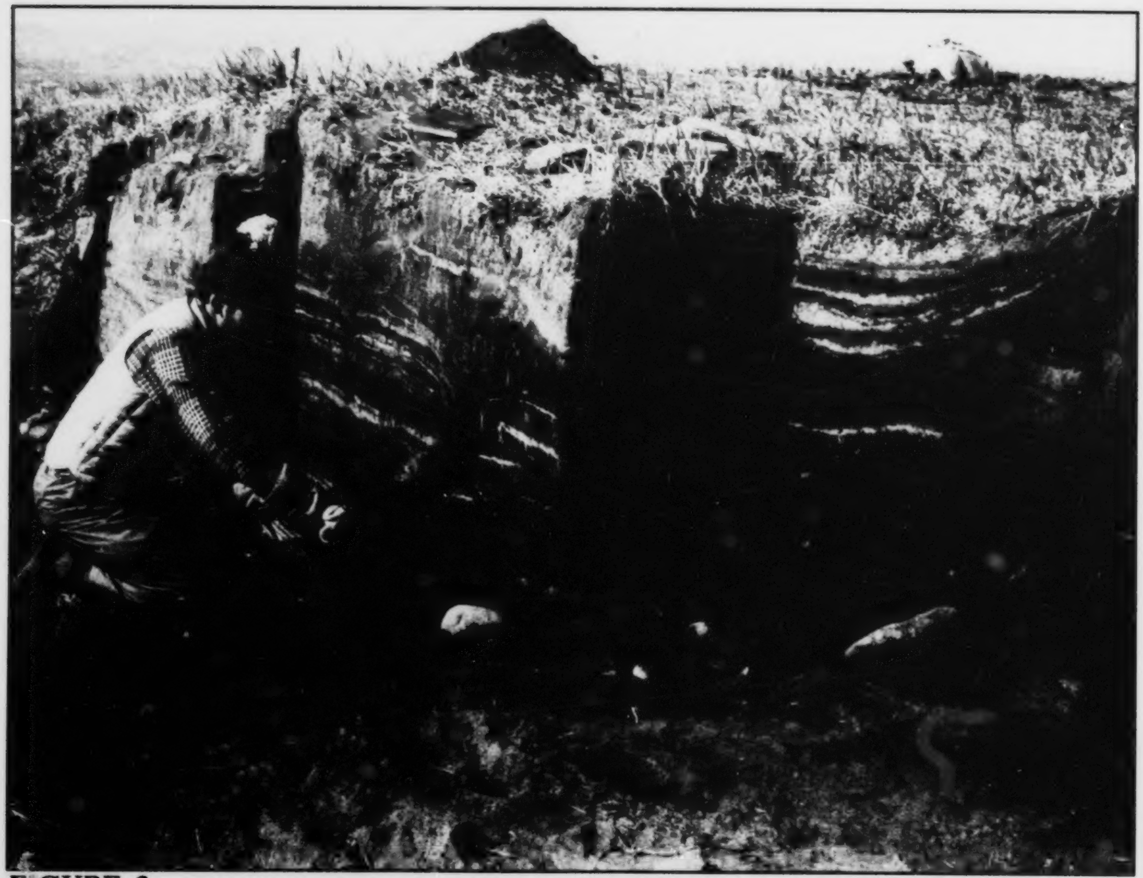


FIGURE 3: Archaeologist uncovering the remains of the Nelson River Thule house buried beneath approximately 1 m of overburden.

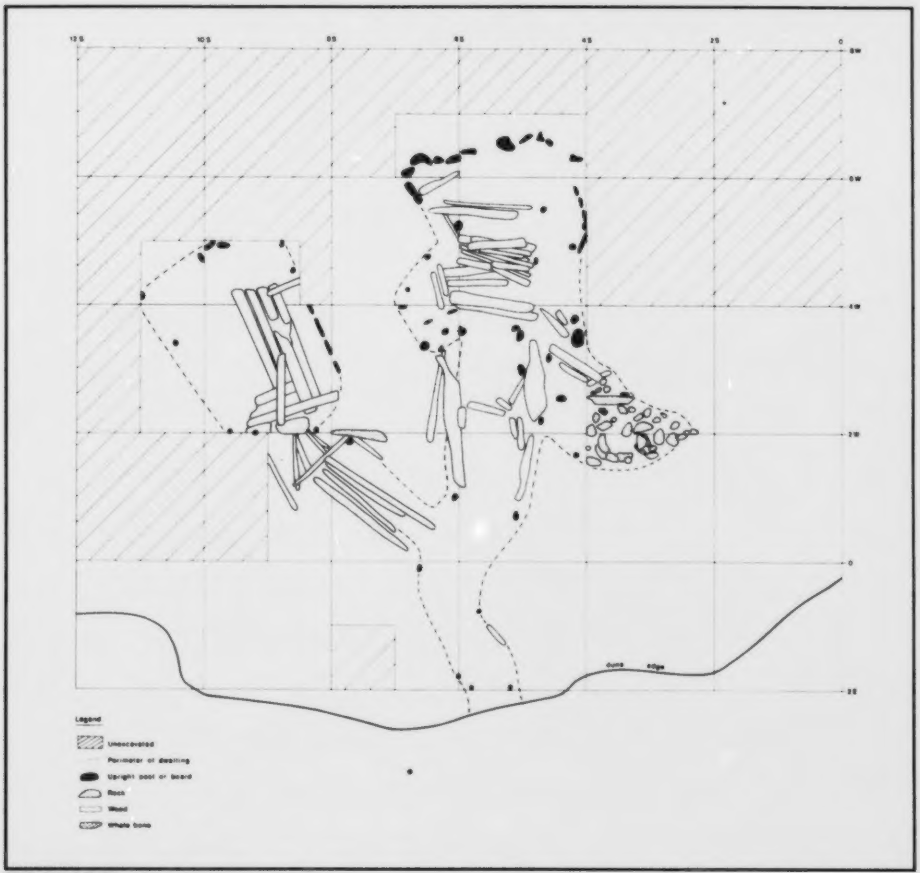

12S
10S
8S
6S
4S
2S
0
8W
6W
4W
2W
0
2E
dune edge
Legend
Unexcavated
Perimeter of dwelling
Upright post or board
Rock
Wood
Whale bone

FIGURE 4: **Plan view of the remains of the Nelson River house. Driftwood was used almost exclusively in the construction of the dwelling.**

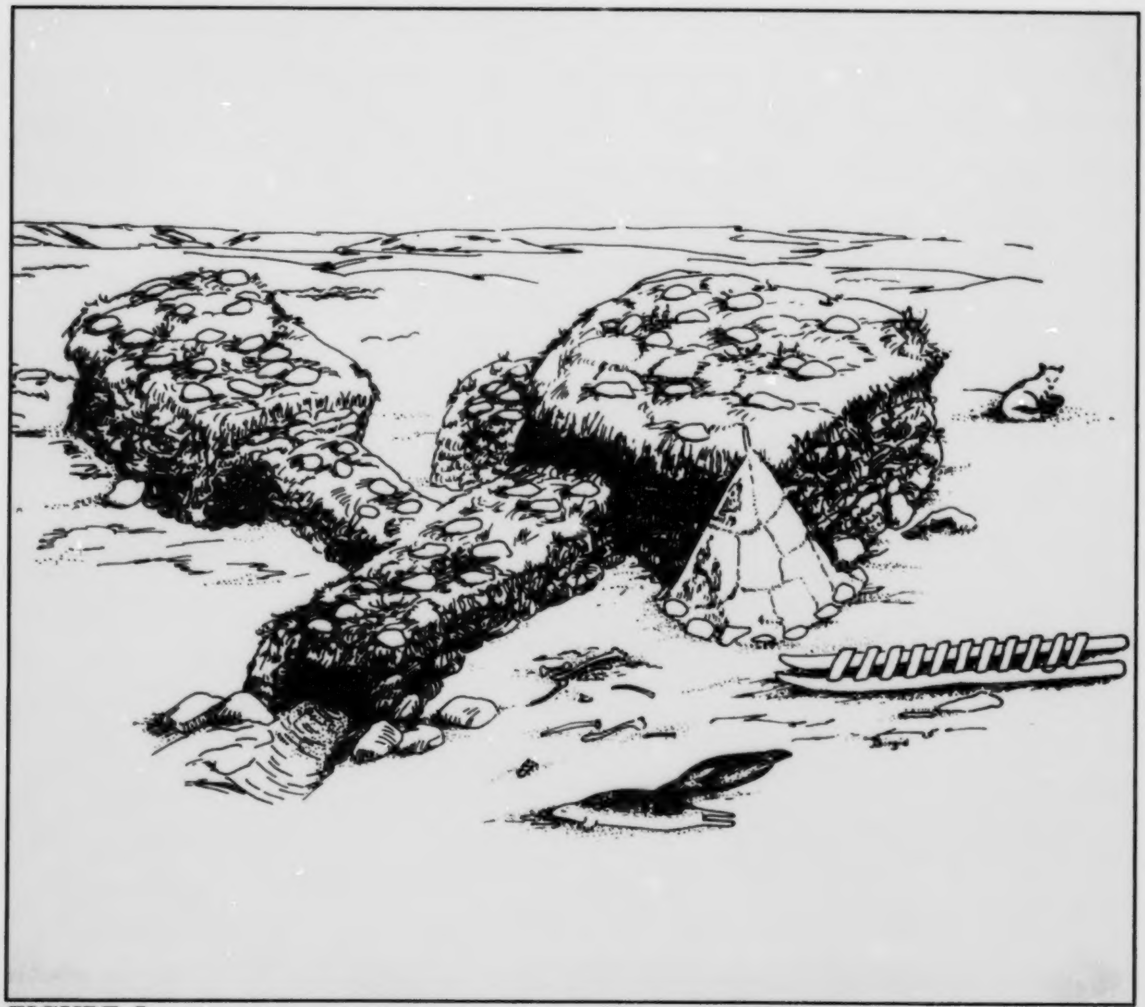


FIGURE 5: Artist's reconstruction of the driftwood Nelson River house, covered over with an insulating layer of turf.

More than 20,000 bones were excavated from the interior of the house and from an outside midden. A 10% sample was analyzed, on the assumption that this would clarify the overall economic pattern of the Nelson River Thule people (Figure 6). In terms of overall contribution to their diet, hunting sea mammals was of paramount importance. Ringed seals were by far the most frequently killed species, although bowhead whales probably contributed a larger amount of meat and oil (Savelle and McCartney, this volume). Even with this emphasis on sea mammals, the faunal assemblage showed that probably most of the vertebrates in the area had been hunted. Notably absent were fish bones, although we found (to our dismay) that fishing is unproductive near Nelson River. The low frequency of caribou in the assemblage seems anomalous, since caribou skins are almost

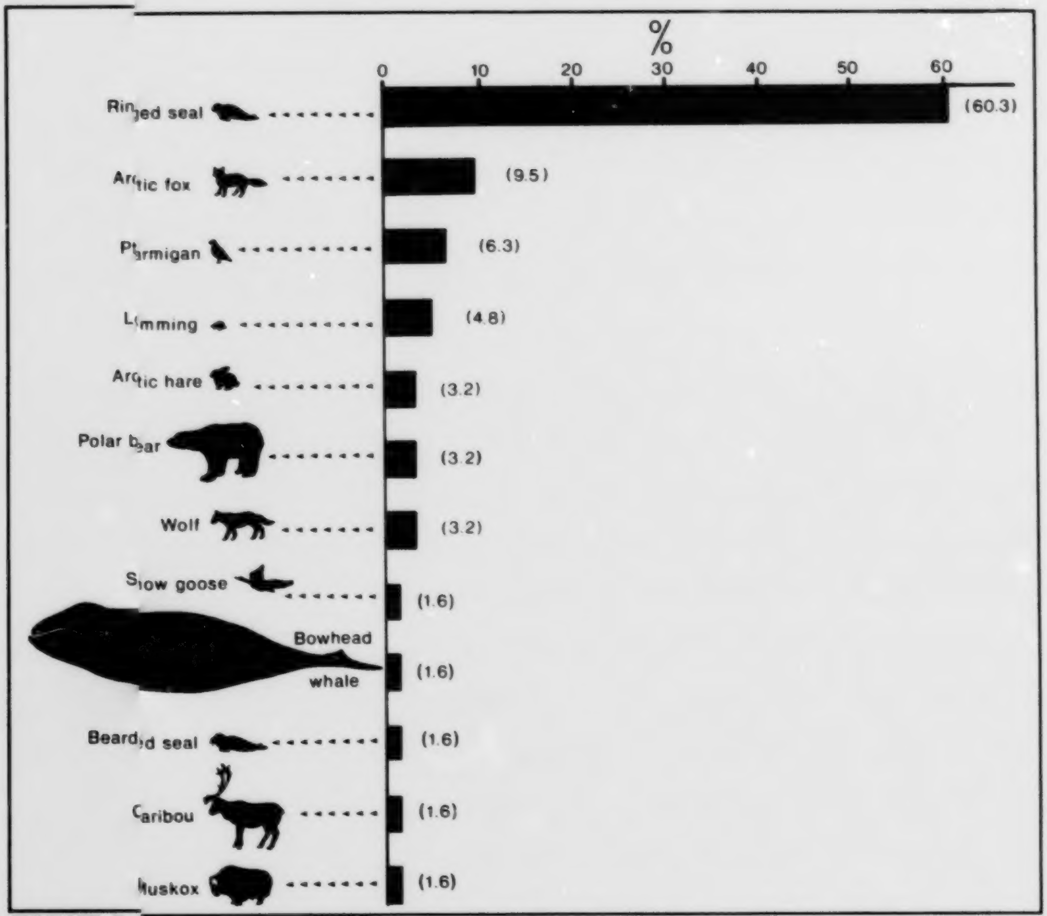


FIGURE 6: Percentages of animal species represented by bones excavated from the Nelson River house.

essential for warm, lightweight winter clothing. Remembering, however, that this was a winter house, and since fall caribou pelts are the most desirable for making clothing, perhaps caribou were hunted earlier in the season, before the Nelson River Thule people moved to their winter quarters.

Abundant artifacts were recovered, representing a variety of hunting and domestic activities (Figure 7). Many artifacts had been made using techniques and materials that were closely related to Alaskan tool industries. Tools made of wood, and for working wood, were common. This reflects a ready access to driftwood, which is characteristic of Alaskan Thule. Many of the stone tools were shaped by flaking, a common western technique, although ground stone tools of the kind that later dominated the stone tool industry of the eastern Arctic Thule culture were also found. Lamps and cooking pots were made from clay - a common western Arctic trait - rather than from soapstone which was usually used for these purposes farther east.

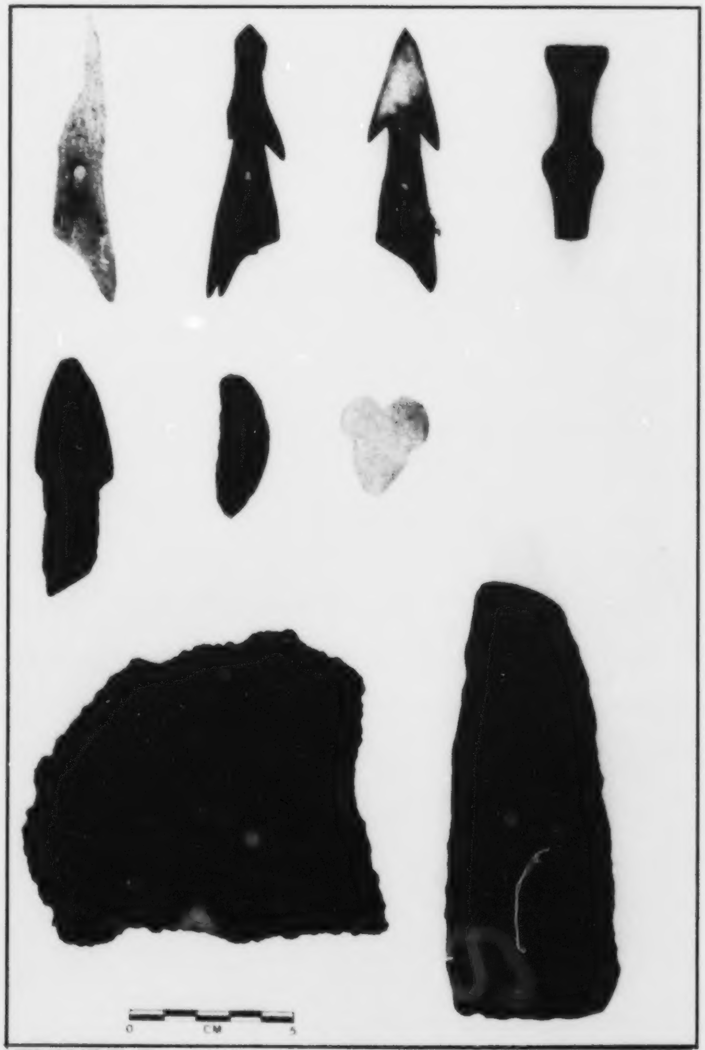


FIGURE 7: Artifacts from the Nelson River House. Top (left to right): harpoon heads, some of which retain Birnirk traits, Alaskan-style needle-case. Middle (left to right): ground stone knife blade, chipped stone scraper, whale effigy? Bottom (left to right): pottery sherd, adze blade.

The kinds of artifacts found are much like those made by the late Birnirk and early Thule peoples in Alaska. Harpoon heads in particular show this affiliation, suggesting a fairly early date for the Nelson River site. Radiocarbon age determinations support this suggestion. The average uncorrected date on four samples is 920 AD, with a correction factor advancing that date to 940. The transition from Birnirk to Thule is thought to have happened about 900, so apparently the Nelson River site was occupied shortly after that event.

To summarize, the Nelson River site is not far removed culturally or geographically from Birnirk in northern Alaska. For instance, the people who lived there retained the use of driftwood for housing and woodworking, made stone tools by flaking and by grinding, and used pottery. Specific artifact resemblances are apparent as well.

There are differences, too. Erosion at the Nelson River site has destroyed some of the houses, but we can guess by the generally small size of other house clusters in the area that it was smaller than most Birnirk settlements. Smaller camp sizes are predicted by McGhee's model for the transition from ice-lead to open-water whale hunting. Whales are less concentrated in the open water, and if the hunt should be unsuccessful the group's chances of survival are maximized if it is small enough to be sustained by other resources. Further differences include new and changed artifact types, but they are expected as adjustments are made to new environmental situations, and as lines of communication with people on the north Alaskan coast became attenuated.

The Nelson River site, then, conforms well to McGhee's model for Thule development and expansion. In its first phase this involved a shift into an area not too different from the north Alaskan homeland of the Thule culture, although new hunting strategies and resultant patterns of settlement were required. Other archaeological sites in the western Canadian Arctic, including several elsewhere on Banks Island, southern Victoria Island and on the mainland coast near Cape Parry, show that the Nelson River cultural configuration was not unique, and that this early pioneering movement was successful in colonizing the eastern margins of the Beaufort Sea.

Ruin Island Thule

The expansion of early Thule culture into the Canadian Beaufort Sea region was only the first step in its spread through most of the Canadian Arctic. Recent archaeological investigations of Thule culture sites in the vicinity of Alexandra Fiord on Ellesmere Island (at the eastern end of the Canadian Arctic; Figure 1) have revealed evidence of another, later pioneering episode.

The relatively low, dissected plateau area around Alexandra Fiord (79° North) represents one of the few, major unglaciated areas along the mountainous east coast of Ellesmere Island. Skraeling Island, near the entrance to Alexandra Fiord, contains two large Thule culture winter settlements with over 40 house ruins relating to various stages of occupation.

The earliest Thule culture houses on Skraeling Island belong to a distinctive period known as the Ruin Island phase, after an island by that name located off the coast of northwestern Greenland where its remains were first discovered in the early 1930s by the Danish archaeologist, Erik Holtved. The Ruin Island phase is characterized by a distinctive winter dwelling and by the retention of many western-related traits such as: Alaskan-style needle cases; harpoon heads with ornamental spurs and western design motifs; and the use of pottery for vessels and lamps.

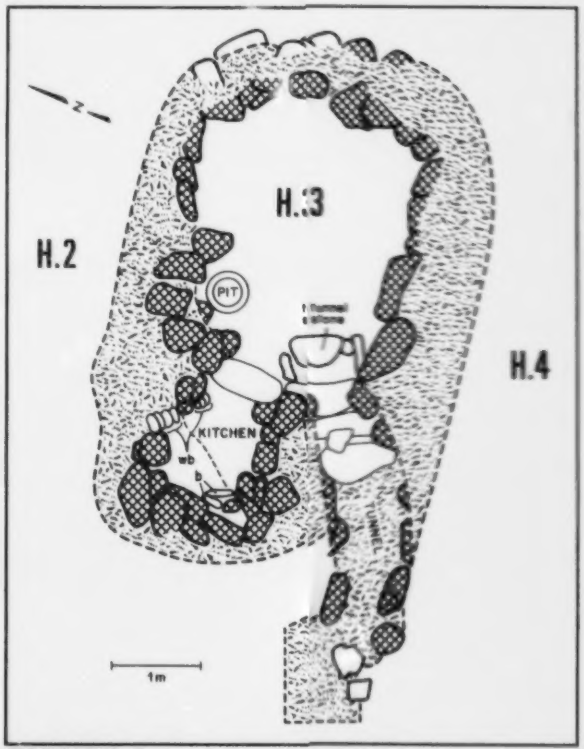


FIGURE 8: Skraeling Island Site, House 3.

The typical Ruin Island winter dwelling was half-buried (semi-subterranean) with broad exterior walls constructed of a double row of boulders (Figure 8). Since drift-wood logs were scarce on eastern Ellesmere Island, large boulders and bowhead whale bones were used as structural supports for the roof which was covered with a thick, insulating layer of sod. The floor of the main room was generally unpaved except for a single piece of stone flagging which marked the edge of the sunken entrance passage (Figure 9). The presumed sleeping area at the back of the main room was marked by a slight rise in the sandy gravel floor, with a thin layer of heather used as part of the bedding. In a few cases, slab-stone sleeping platforms supported by stone uprights were built, although this was a more common occurrence in later Thule winter houses. The most distinctive feature of the Ruin Island winter houses was the construction of a separate kitchen extension paralleling the entrance passage (Figure 10). Each kitchen

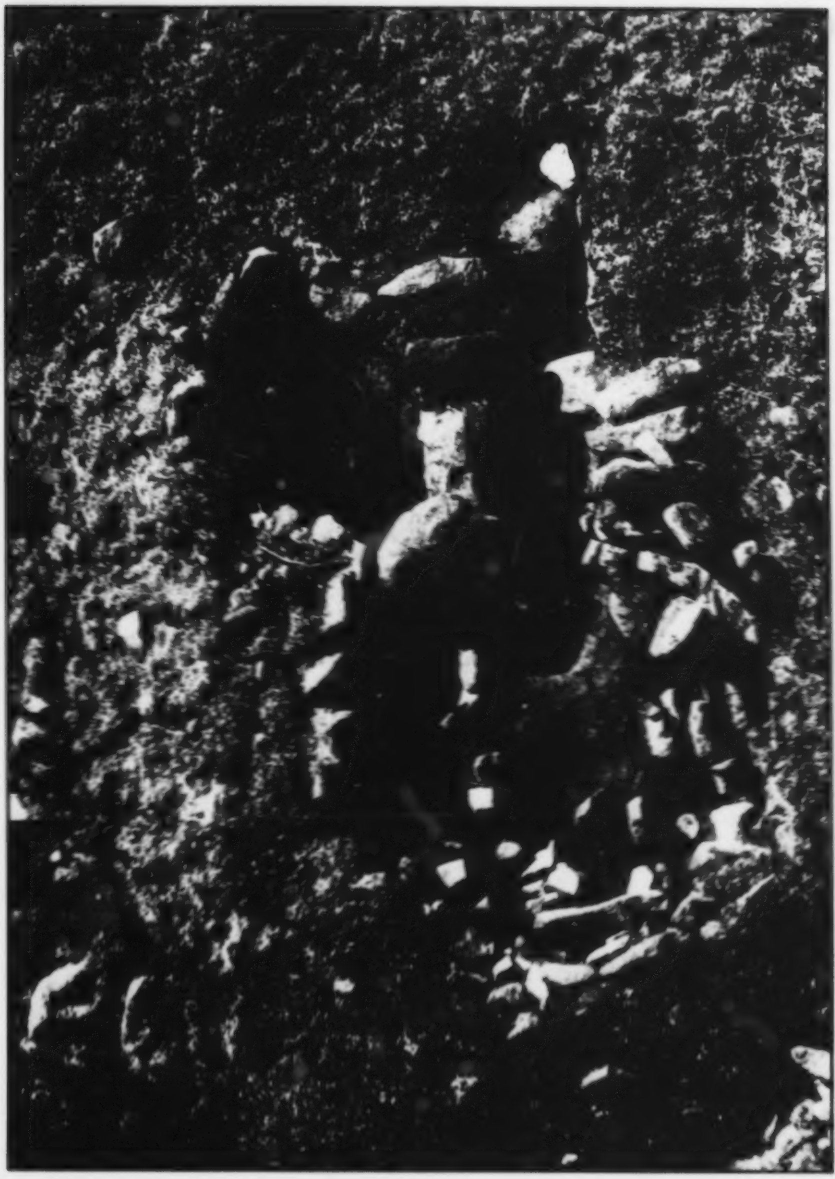


FIGURE 9: Aerial view of House 6, Skraeling Island Site.

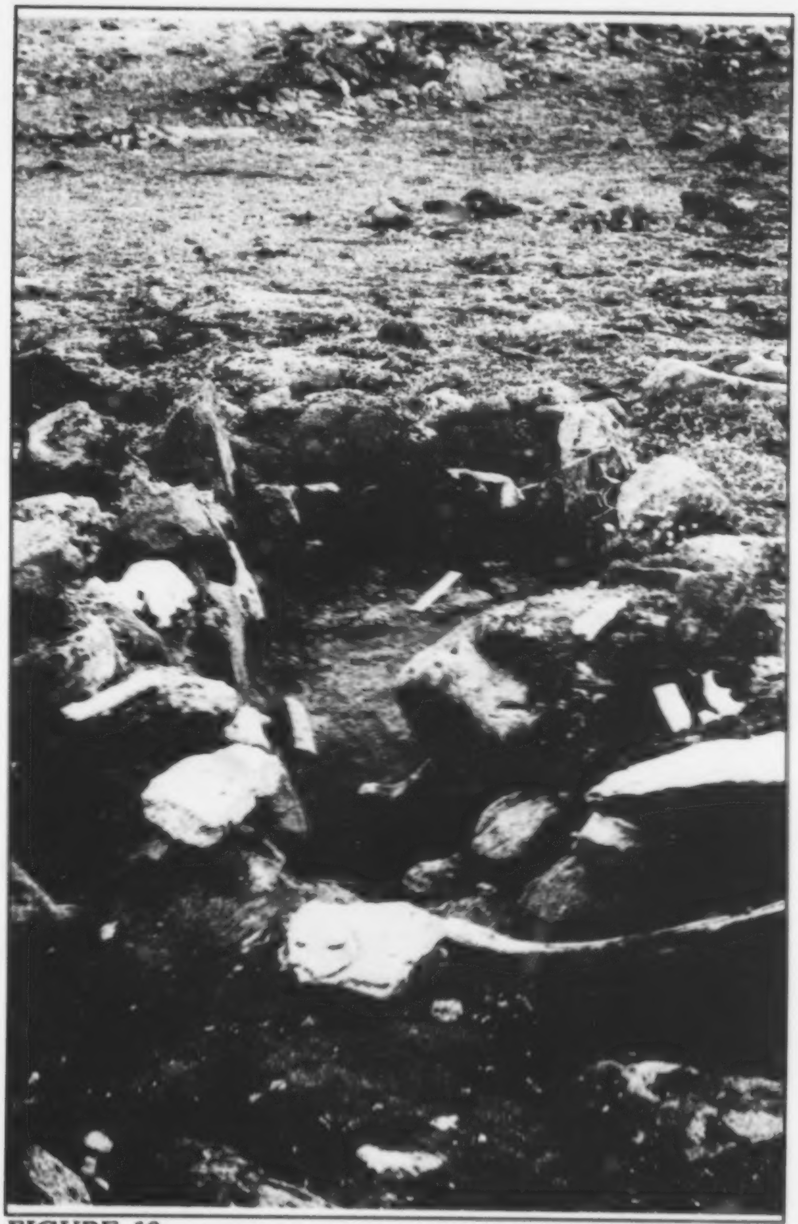


FIGURE 10: Skraeling Island Site, House 11, kitchen.

had its own short entrance, often capped with one or two boulders. This suggests that the kitchen was roofed separately from the main room, perhaps with a skin flap allowing smoke to escape. The small kitchens contained raised platforms where food was cooked over open fires fuelled by bone, wood and marine mammal oil (Figure 11).

The analysis of over 15,000 identifiable mammal and bird bones from the winter house ruins shows that, like the people who lived at Nelson River, the Thule inhabitants of Skraeling Island depended mainly on sea mammals, particularly ringed seal, for their livelihood. Microscopic examination of seal canine tooth thin-sections showed that most seals were killed during spring, summer and fall, suggesting that meat stored in caches may have provided the bulk of winter sustenance. Migratory waterfowl and land mammals such as arctic fox, arctic hare, and muskox lent variety to the predominantly sea mammal diet.

Winter houses with well-defined kitchen extensions, are, to date, unknown in other areas of the eastern Canadian Arctic but are found in contemporaneous Thule sites in western Alaska. The similarities in house form, harpoon-head styles, and several other artifact traits, suggest that the Ruin Island phase represents a migration of people from western Alaska, rather than from the northern coast of Alaska.

Although the western cast of their buildings and artifacts suggest that the Ruin Island phase Thule people were recent immigrants, several radiocarbon age determinations on a variety of material from the Skraeling Island houses indicate an average age of late twelfth or early thirteenth centuries - approximately 200 to 300 years after Thule people had first entered the Beaufort Sea region. Nor were the Ruin Island phase people the first Thule in the eastern Arctic, as archaeological sites in the Barrow Strait/Lancaster Sound region contain evidence of other cultural variants that apparently predate the Ruin Island phase by at least a century. So, while the Ruin Island phase Thule people may have been the first Thule to enter the Alexandra Fiord area, and did so following a rapid migration from Alaska, other Thule groups were already present throughout most of the Canadian Arctic. Thus, archaeological evidence from southern Banks Island, eastern Ellesmere Island and other areas of the central and eastern Arctic suggests that the Ruin Island phase is only one of several pioneering movements from various regions of Alaska into the Canadian Arctic.

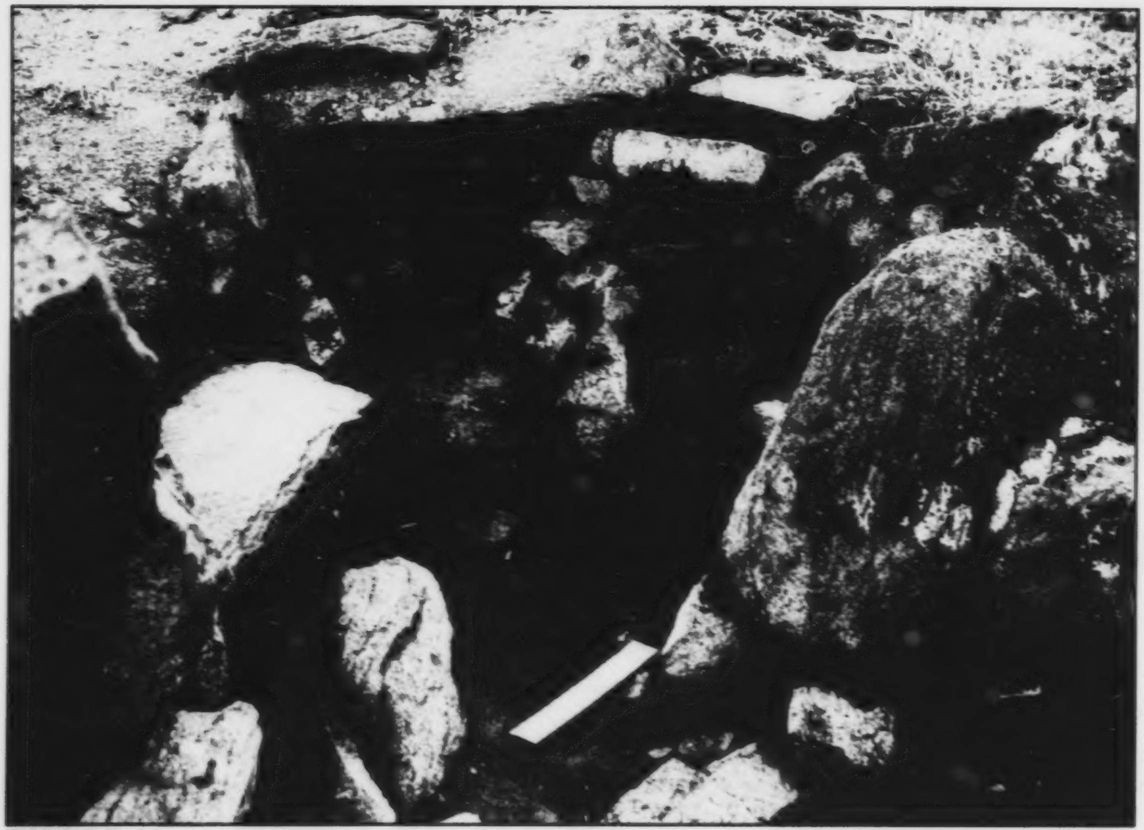


FIGURE 11: Skraeling Island Site, House 5, kitchen cooking platforms.

DISCUSSION

Comparing the Nelson River data with evidence from Skraeling Island shows that no single theory yet advanced satisfactorily accounts for the spread of the Thule culture throughout the Canadian Arctic. The Nelson River data suggest that the earliest pioneering Thule groups simply expanded their range eastward a short distance from Alaska, possibly due to ecological pressures. Seemingly originating from a different area and in a different period, however, the Ruin Island phase migrants do not fit neatly into the ecologically-based model for the expansion of Thule. Other causes which could account for their appearance in the east include a search for raw materials such as iron, depletion of resources in their former territory, or troubles in their homeland, such as feuding.

One can search for other explanations to account for this later wave (or waves) of migrants, but more productive lines of inquiry can be pursued as well. Archaeologists are interested in studying these migrations not only because of our curiosity about how cultures came to be in a particular place, but also because migrations are themselves strong causal factors promoting cultural change. For as long as Inuit have been known to a wider world, anthropologists and ethnologists have marvelled at their adaptability, which is shown in part by accommodation to particular conditions found in different parts of the Arctic. The time depth added by archaeology lets us see that migrations which brought people into contact with fresh environmental situations stimulated new cultural responses. This, in turn, contributed to the diversity which eventually came to characterize regional Inuit groups. Further, if we are correct in reading the evidence from Nelson River, Alexandra Fiord and elsewhere as indications that the Thule ancestors of the historic period Inuit stemmed from several different parts of the Alaskan homeland at different times, we can see this, too, as a factor in the emergence of cultural diversity in the Arctic.

ACKNOWLEDGEMENTS

The archaeological work on Banks Island was undertaken by Charles Arnold and funded by the Social Sciences and Humanities Research Council of Canada and the University of Toronto Connaught Fund. Karen McCullough and Peter Schledermann directed the

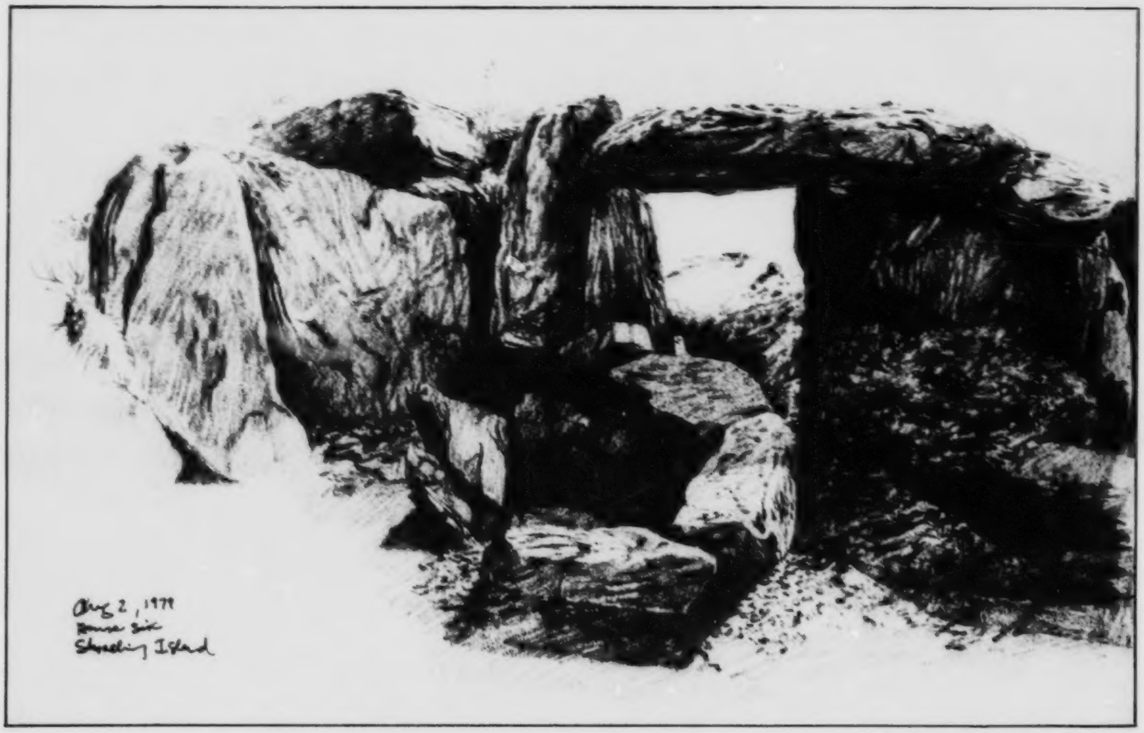
Ellesmere Island archaeological investigations with financial assistance from the Social Sciences and Humanities Research Council of Canada, the National Geographic Society and the Arctic Institute of North America. The Polar Continental Shelf Project provided logistic support for both projects.

REFERENCES

Arnold, C. 1986. In search of the Thule pioneers. In: Thule Pioneers. Edited by: E. Bielawski, Carolynn Kobelka and Robert Janes. Prince of Wales Northern Heritage Centre, Occasional Papers No. 2:1-93.

McGhee, R. 1969-1970. Speculations on climatic change and Thule culture development. Folk 11-12:173-184.

McCullough, K.M. 1986. The Ruin Island phase of Thule culture in the eastern High Arctic. Unpublished Ph.D. dissertation, University of Toronto, Toronto, Ontario.



Aug 2, 1979
House six
Skraeling Island

Illustrated by Brenda Carter

PREHISTORIC THULE ESKIMO WHALING IN THE CANADIAN ARCTIC ISLANDS: CURRENT KNOWLEDGE AND FUTURE RESEARCH DIRECTIONS

James M. Savelle[1] and Allen P. McCartney[2]

Abstract: Prehistoric Thule Eskimo subsistence in the Canadian Arctic Islands is often considered synonymous with bowhead whaling, due to the highly visible and impressive remains of winter dwellings constructed from bowhead whale bones. Despite the considerable body of data relating to Thule culture that has been compiled since its initial definition and description in 1927, the role of the bowhead whale in the Thule subsistence economy is poorly understood. Indeed, many researchers consider an assessment of its importance beyond our present interpretative capabilities.

Here, we outline the nature of archaeological whale bone and review past interpretations of Thule subsistence and bowhead whaling. Bowhead whales are then examined as part of the Thule economy, within the context of recent human ecological models. Specifically, by analyzing Thule whaling from the perspective of predator-prey relationships and economic zonation strategies, bowheads are shown to be central to the economy of Thule Eskimos living beside many major straits and bays of the central and eastern Canadian Arctic. In doing so, we emphasize the importance of expanding future Thule subsistence studies to include a regional, as opposed to a site-specific approach.

Archaeological whale bones are useful evidence of the range and relative frequency of bowheads in different parts of the Canadian Arctic prior to commercial whaling. Archaeology provides material remains of bowheads that lived some 700-800 years before those described in whalers' journals and explorers' accounts of the nineteenth century. While bowheads of the historic period are loosely documented, they are not represented in material form for further examination today. Thus, archaeological whale bones furnish whale biologists with valuable diachronic data about these largest of arctic mammals that were almost extinguished by nineteenth and early twentieth century commercial whaling.

Résumé: La survie des Eskimos préhistoriques de Thulé dans les îles de l'Arctique canadien est souvent associée à la chasse à la baleine boréale, à cause des restes hautement visibles et imposants d'habitations d'hiver construites d'os de baleines boréales. Malgré le grand nombre d'informations compilées sur la culture de Thulé depuis sa première définition et description en 1927, le rôle de la baleine boréale dans l'économie de subsistance de Thulé n'est pas bien compris. En effet, bien des chercheurs croient que l'évaluation de son importance dépasse nos capacités d'interprétation actuelles.

Tout d'abord, nous donnons un aperçu de la nature de l'os de baleine, sur le plan archéologique, puis nous passons en revue les précédentes interprétations de l'économie de subsistance et de la chasse à la baleine à Thulé. Par la suite, nous examinons les baleines boréales et leur rôle dans l'économie de Thulé, dans le contexte de récents modèles écologiques de l'espèce humaine. Plus spécifiquement, lorsque l'on fait l'analyse de la chasse aux baleines de Thulé du point de vue des relations prédateurs-proies et des stratégies de zone économique, les baleines boréales apparaissent comme le pivot de l'économie des Eskimos de Thulé vivant à proximité des principaux détroits et baies du centre et de l'est de l'Arctique canadien. Cette manière de procéder met l'accent sur l'importance d'élargir les futurs champs de recherche sur la subsistance de Thulé, de manière à adopter une approche axée sur la région plutôt que sur le site même.

Les vestiges d'os de baleines apportent des preuves utiles sur le territoire et la fréquence relative des baleines boréales dans les différentes parties de l'Arctique canadien avant l'apparition de la chasse commerciale. L'archéologie offre des restes physiques de ces baleines qui existaient quelque 700 à 800 ans avant celles décrites dans les journaux des pêcheurs de baleine et dans les comptes rendus des explorateurs du 19e siècle. Cependant, bien qu'il existe une vaste documentation sur les baleines boréales de la période historique, on ne retrouve plus, de nos jours, de restes matériels pour les étudier plus à fond. Par conséquent, les vestiges des os de baleines apportent aux biologistes des données diachroniques de prix sur ces mammifères les plus gros de l'Arctique, dont l'espèce a été presque détruite par la chasse commerciale à la baleine au 19e siècle et au début du 20e siècle.

INTRODUCTION

Prehistoric Thule Eskimos of the Canadian Arctic (about 1000-1600 AD) are often considered to be preeminent whalers. The initial development of Thule culture in Alaska prior to about 1000 AD, the migration of Thule Eskimos across northern Canada and into

---

[1] Department of Anthropology, McGill University, Montreal, Quebec H3A 2T7
[2] Department of Anthropology, University of Arkansas, Fayetteville, AR 72701, U.S.A.

prior to about 1000 AD, the migration of Thule Eskimos across northern Canada and into Greenland (Arnold and McCullough, this volume), and the subsequent 'decline' of the human population and abandonment of the High Arctic between approximately 1400-1600 AD, for example, have all been directly related to bowhead whale availability. This paper: (1) reviews the evidence for Thule whaling as traditionally presented; (2) reviews past interpretations of this evidence; (3) introduces a study that we feel can contribute to a more comprehensive understanding of Thule whaling; and (4) suggests ways that whale bone data are of use to cetacean biologists.

THE BOWHEAD WHALE AS A PREY SPECIES

The bowhead whale (*Balaena mysticetus*) is, in several respects, unique in the Arctic Islands as a prey species. These animals are by far the largest of arctic mammals, with mature adults attaining lengths of up to 20 m (Nerini *et al.* 1984) and weighing up to 40,000-50,000 kg. Furthermore, the very large size of the individual bones of the skeleton (Figure 1) make them ideal for construction materials for dwellings in an area lacking trees or significant quantities of driftwood. Finally, bowhead whales are slow swimmers (averaging 2-4 knots), feed near the surface, are relatively easy to approach,and float remarkably well when killed (McVay 1973; Marquette 1978; Reeves *et al.* 1983). Three separate bowhead stocks are known in the Canadian Arctic during historic and recent times: Beaufort Sea, Davis Strait, and Hudson Bay stocks (Mitchell 1977; Mitchell and Reeves 1982). Each of these had a separate commercial whale fishery (Ross 1979).

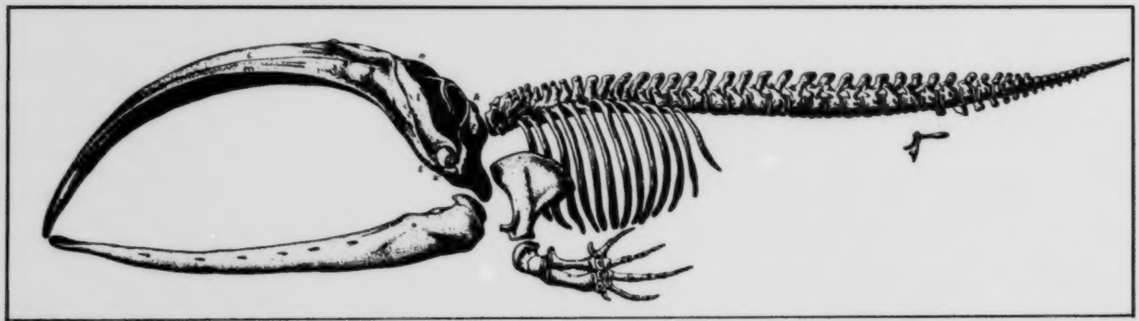


FIGURE 1: **Bowhead whale (Balaena mysticetus) skeleton, showing the relative size of the various elements. (From Scammon 1874; based on an original drawing published in 1866 by D.F. Eschricht and J.Reinhardt).**

Given that the most important attributes to hunter-gatherers in determining prey species are weight, density, aggregation, mobility, fat content, and non-food yields (Jochim 1976, p. 7, 23 and following pages), the bowhead whale is an obvious prey choice, given an appropriate technology.

TRADITIONAL EVIDENCE FOR THULE WHALING

Thule culture was originally defined and described by Therkel Mathiassen (1927), and the presence of architectural and other whales bones and baleen in winter house sites (Figures 2, 3) influenced Mathiassen's interpretation of the culture:

> "Whaling has apparently been one of the principal occupations; this is proved both by the construction of the houses, in which whalebones play such a great part, and by the material used for implements, whalebone and baleen apparently being the most important; in particular, however, the composition of the refuse heap, the large masses of baleen and whalebones which appear especially in the lower strata, indicate that whaling has been one of the most important means of livelihood of the population. The hunting of other marine mammals, especially walruses and seals, has also been of great importance to them, and the same may be said of caribou hunting." (Mathiassen 1927A, p. 85)".

While Mathiassen did not ignore non-whaling variants of Thule culture, noting for example that Thule Eskimos at Malerualik on King William Island "... based their lives upon caribou hunting, whereas marine mammal hunting retired into the background" (Mathiassen 1927A, p. 321), there is no question that, for the most part, he interpreted large baleen whale hunting as the primary subsistence activity. This is undoubtedly due to the fact that the major prehistoric sites he studied (Naujan at Repulse Bay, and Qilalukan and Mitimatalik at Pond Inlet) were on waters frequented by bowheads, thus making them available to prehistoric hunters.

The evidence for Thule whale hunting (in contrast to using stranded carcasses) includes direct and indirect evidence (see McCartney 1980A for detailed discussion).

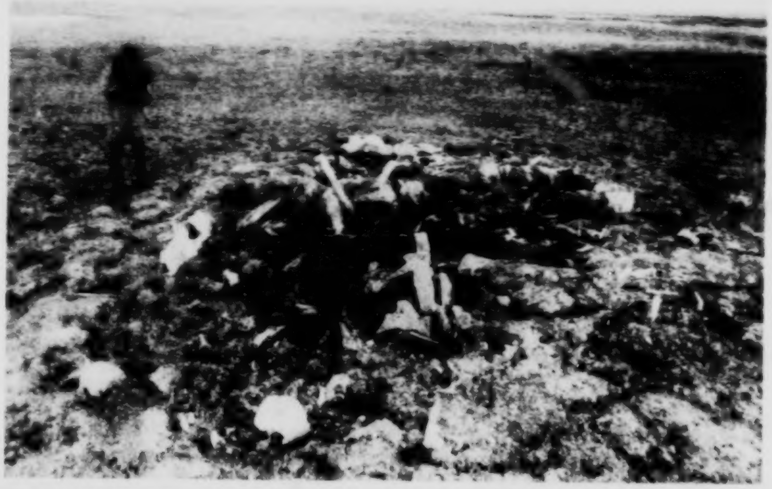


FIGURE 2: A winter house ruin at the PcJq-5 (Cape Garry) site, southeastern Somerset Island. Jumbled stones and whale bones lie scattered from the original house construction.

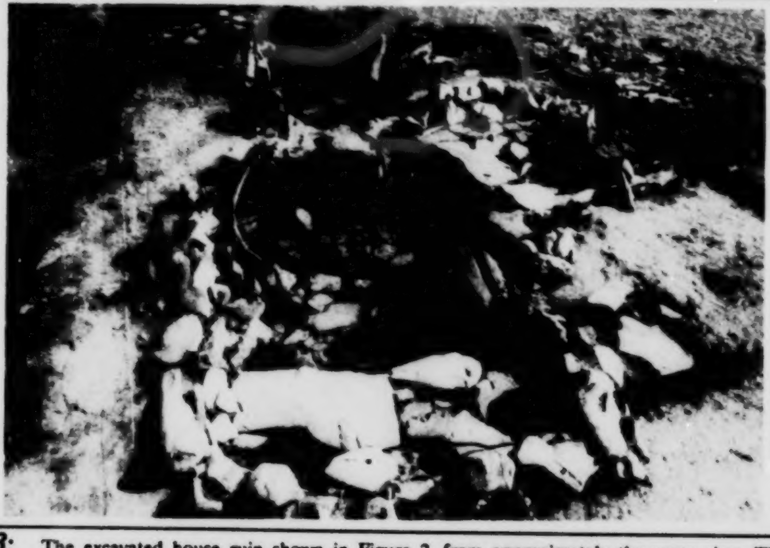


FIGURE 3: The excavated house ruin shown in Figure 2, from approximately the same view. The entranceway (upper) is flanked by four whale skull bases and enters the house proper through the linteled doorway. Two platforms face the flagstone floor, one at the rear (lower) and one at the right side of this view. The string grid sections measure 2 x 2 m.

Direct Evidence

Direct evidence for whaling includes the presence of specialized whaling gear and depictions of whaling scenes.

Specialized Whaling Gear

Thule has been described as one of the most gadget-oriented of prehistoric cultures (Maxwell 1985, p. 262), and several Thule implements have been identified as having been used specifically for whaling. Whaling gear originally identified by Mathiassen (1927A) includes whaling harpoon heads, whaling harpoon foreshafts, whaling lance heads, and whaling harpoon and lance endblades. While rare in archaeological contexts, these items have been recovered from Thule sites in Alaska, the Canadian Arctic, and Greenland.

Depictions of Whaling Scenes

Although pictorial representations of Thule Eskimo activities on artifacts are rare, at least five have been recovered that depict scenes of active whaling (Collins 1951, p. 63; McCartney 1980A, p. 523; McGhee 1984, p. 76; Maxwell 1983, 1985, p. 268). Four of these show umiak crews in the process of chasing or harpooning bowhead whales (Figure 4), while the fifth (Maxwell 1985, p. 268) depicts a bowhead whale being towed tail-first by an umiak.

Indirect Evidence

In addition to direct evidence, there are also various forms of indirect evidence for whaling. These are outlined as follows.

Site Location

Besides the occurrence of whale bone and baleen in considerable quantities at many Thule winter sites, the location of these sites corresponds closely with the historic (and probably prehistoric; see Harington, this volume) distribution of bowhead whales. Thule sites which contain few little or no bowhead whale products, on the other hand, correspond closely with those areas where bowheads were historically absent or only occasionally reported. This correspondence may be seen on a larger scale for the Canadian Arctic

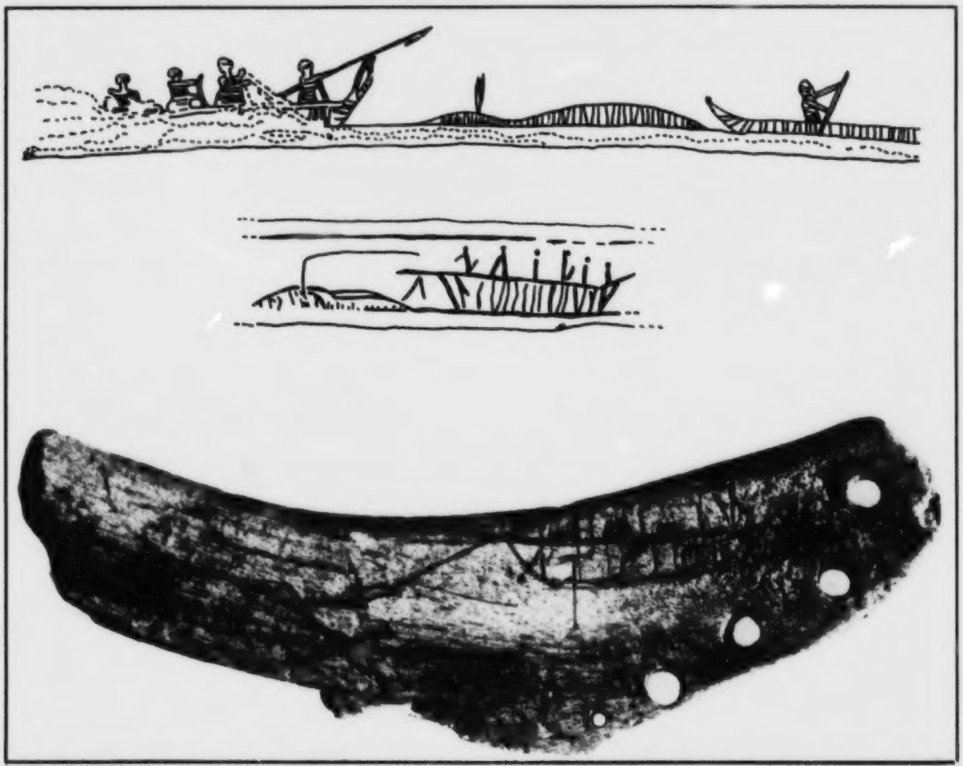


FIGURE 4: Depictions of Thule whaling scenes from the Canadian Arctic. Upper: Scene from an ivory bow drill handle found by Father Guy Mary-Rousseliere and Lawrence Oschinsky at a site on Admiralty Inlet, Baffin Island. Middle: Scene from an ivory bow drill handle found by Peter Schledermann at a site near the head of Cumberland Sound, Baffin Island. Lower: Scene from a snow knife handle piece found by Henry Collins at a site near Resolute Bay, Cornwallis Island. (Drawings by Phyllis Clancy; photo courtesy of Henry Collins and the Department of Anthropology, Smithsonian Institution).

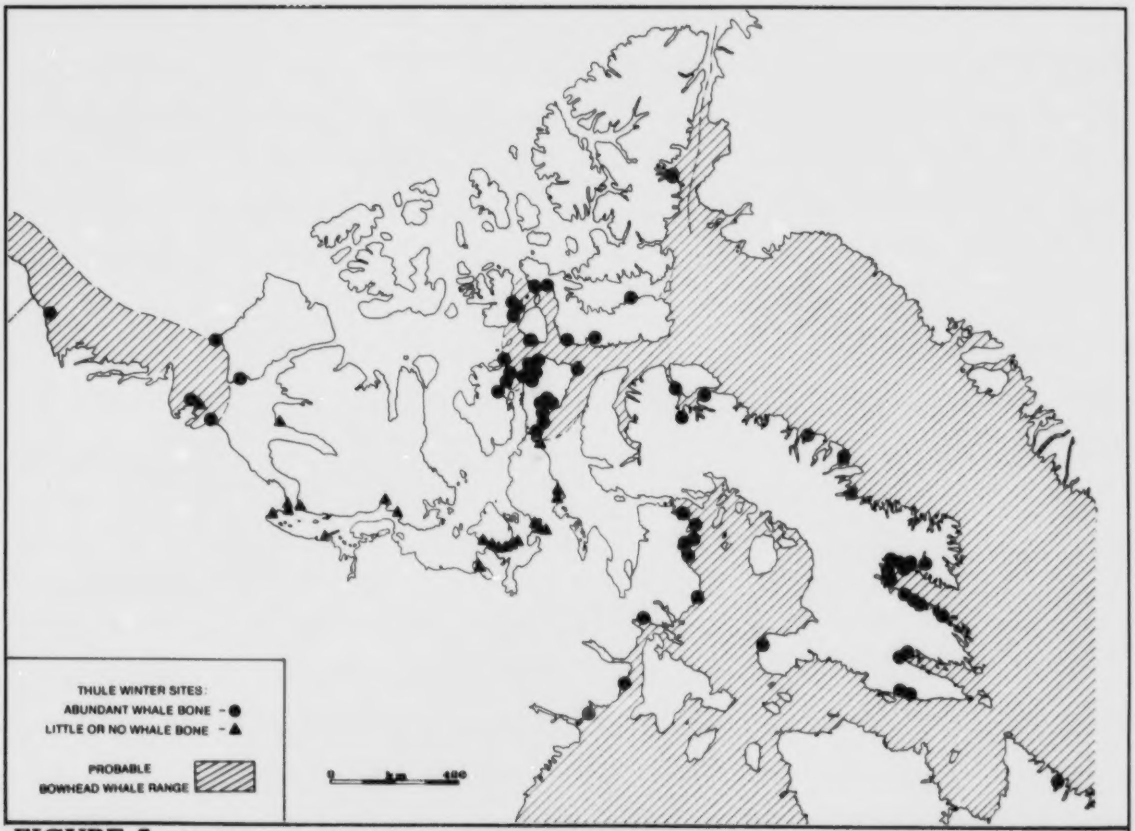

THULE WINTER SITES:
ABUNDANT WHALE BONE - ●
LITTLE OR NO WHALE BONE - ▲
PROBABLE BOWHEAD WHALE RANGE ▨
0 km 400

FIGURE 5: **Distribution of whale bone at permanent winter sites in relation to the probable contemporary bowhead whale range. Sites with little or no whale bone are shown for the areas bordering or outside the bowhead whale range only.**

(Figure 5), or on a small scale such as the Boothia Peninsula-Somerset Island area (McCartney and Savelle 1985, p. 52).

Resource Utilization

The massive size of even immature bowheads, such as those we have measured at Somerset Island sites (see below) that averaging about 8.5 m long and probably weighing 10,000-12,000 kg, totally overshadowed all other available fauna. Conservatively assuming that half of an immature whale's weight was usable as meat and blubber, then the resulting 5,500 kg of edible food or fuel equalled the usable weight of about 120 caribou or 180 ringed seals. Since bowheads provide so much human and dog food, fuel, and bone and baleen for tools, sled parts, and containers, we would expect Thule Eskimos to pursue bowheads whenever they had the opportunity.

Ethnographic Continuity

Ethnographic analogy has been referred to previously in relation to whaling gear. Another example of analogy between recent and prehistoric features is the *karigi* (men's ceremonial house) that northern Alaskan whaling crews used (Spencer 1959). Several structures that appear to have been *karigi* have been reported from Thule sites (Savelle 1987). These structures are also reported for nineteenth century Canadian Inuit (Parry 1824, p. 284).

Further, because Thule Eskimos were the direct cultural and biological ancestors of recent Canadian Inuit, many of whom whaled in the central and eastern Canadian Arctic, we would expect that native whaling is an old tradition and a subsistence activity practised by the ancestral people. Although early ethnographic accounts of native whaling and associated gear are relatively rare, there are examples such as the writings of Henry Ellis (in the 1740s) for the Hudson Strait Eskimos (Oswalt 1979), and William Parry (1824) for the Central Eskimos that clearly indicate early historic period native whaling before stocks were decimated by Euroamerican whaling.

Permanent Settlements and Associated Meat Caches

Thule winter house settlements were established close to shore, and thus near open summer waters and winter sea ice. From the midden deposits that surround these settlements, the latter appear to have been occupied for many winters. In order to maintain a permanent settlement, in contrast to temporary igloo winter settlements at places where seals were available (as occupied by historic Inuit), there must be a regular and large amount of storable meat for winter consumption. The settlements with whale bones, stone, and peat block houses mark points on straits and bays where bowheads migrated and summered with some regularity (and thus, from the Eskimos' perspective, predictability). The large number of meat caches associated with winter settlements would be used for storing whale meat and blubber acquired during the summer and early fall, as well as smaller game products. Caches are usually of three types: stone cairns above ground; half-buried pits or 'ice cellars'; and simple, shallow depressions excavated in loose gravel. The shallow depressions (Figure 6) are especially common at Thule sites. As many as 200-300 such caches are known from sites on southeastern Somerset Island, and they could have stored the meat and blubber of 15-25 whales (Savelle 1987). Clearly, such storage capacities are consistent only with active whaling rather than the occasional use of stranded whales.

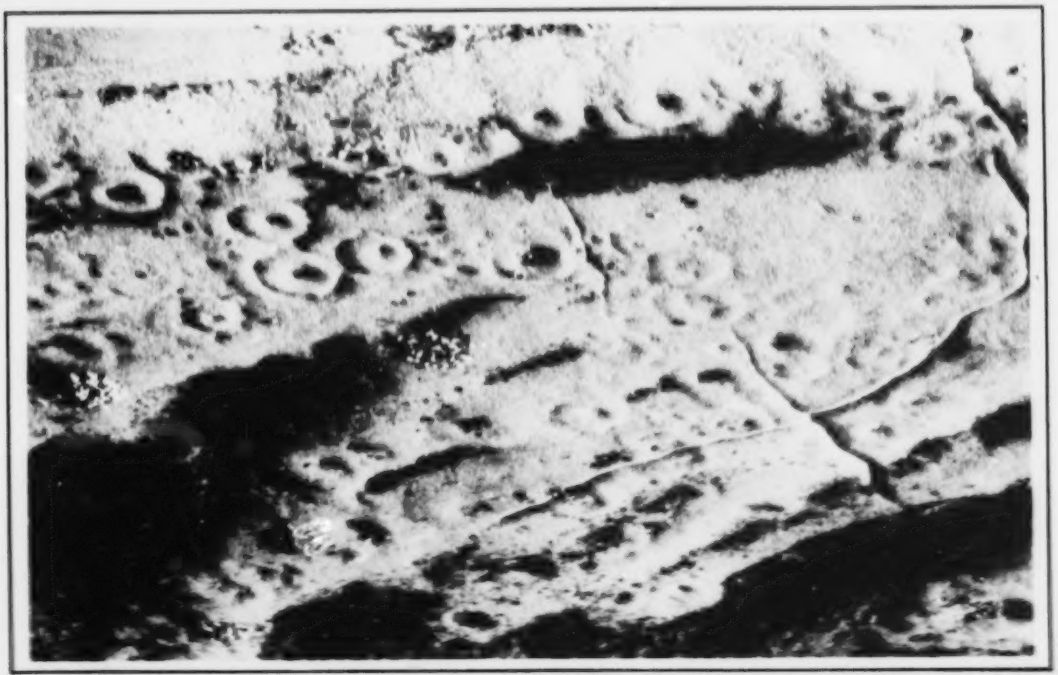


FIGURE 6: Aerial view of surface caches (stone clusters) and subsurface caches at the Pals-2 (Mount Oliver) site, southeastern Somerset Island. (Photo courtesy of Dr. William Kerr, Geological Survey of Canada 1976).

Community Size and Prerequisite Whaling Crews

Thule winter settlements in the central and eastern Canadian Arctic vary greatly in numbers of house ruins (3-50), but 10-20 are common. Even if all the houses were not contemporaneously occupied, probably several umiak crews per settlement could have been organized for whale hunting and towing (Bockstoce 1976).

Prerequisite Sea-Mammal Hunting Gear

No whale hunting using harpoons and drag gear could occur prior to the development of this technology. This gear complex includes inflation nozzles for seal-skin drag floats, wooden bars for lashing floats to drag lines, as well as umiaks and their respective gear (Maxwell 1985, pp. 266-267). Although the various float items and umiaks could also serve in the procurement of smaller sea mammals, they and more specialized whale harpoons and lances were available for use on bowheads (Bockstoce 1973).

Whale Bone Modification

Diet-related butchering marks on whale bones have rarely been recorded, primarily because it is extremely difficult to distinguish such modifications from marks related to shaping and working whale bones for house construction and/or tool manufacture. However, one type of whale bone alteration has been reported that does suggest butchering related to soft organ extraction. During excavations and surveys of Thule sites on southeastern Somerset Island, McCartney (1980A) found that 125 of 129 crania examined exhibited a large, irregular hole in the braincase just superior or anterior to the foramen magnum. Savelle (1987) found similar modifications on 94 of 98 crania examined in the same area. Many of these holes shows definite chop-marks, and the most likely interpretation of such modification is for brain extraction, or possibly the symbolic release of the whale's soul. Both interpretations would be consistent with active hunting. Some of the holes, on the other hand, lack definite chop marks and may have resulted from drying and cracking of the thin supraoccipital bones (McCartney and Savelle 1985, p. 46).

PAST INTERPRETATIONS OF THULE WHALING

Mathiassen's (1972) original interpretation of Thule subsistence stressed bowhead whaling to the extent that it could be considered the "preeminent facet of Thule economy" (Maxwell 1985, p. 248). Furthermore, he suggested a western Arctic (Alaska-Siberia) origin for Thule culture, partly on the basis that in that area only was there sufficient wood to construct umiaks (used in whale hunting). Jenness (1940), following Mathiassen, equated the eastward expansion of Thule culture with whaling. Further, Jenness suggested that Thule culture replaced the preceding Dorset culture (which Mathiassen at that time did not recognize) in the central and eastern Arctic, primarily due to the greater ecological advantage enjoyed by the latter as a result of whaling and dog-sled traction (Taylor 1963).

The whaling emphasis of Thule subsistence was further reinforced by Larsen and Rainey (1948), who, on the basis of excavations in Alaska, introduced the term "Arctic Whale Hunting culture", which in turn included Thule as a "phase".

Since Mathiassen's pioneering study, dozens of preliminary reports and site monographs on the Thule culture have appeared, especially over the past three decades (see for example Dekin 1978, Savelle 1980, Morrison 1983, and particularly Maxwell 1985 for summaries of the history of research). Excavation of Thule sites in the Canadian Arctic, such as those by Collins at Frobisher Bay (Collins 1950) and Resolute Bay (Collins 1951, 1952, 1955), Lowther (1962) at Cape Sparbo, and Manning (1956) on Banks Island all appeared to confirm the "preeminent facet" of Thule whaling. Although not disputing the hunting of bowhead whales per se, Taylor (1966) was the first to stress that not *all* Thule Eskimos were whale hunters. Instead, he suggested that Thule society could best be classified as "omnivorous", such that "... the degree to which different species are exploited reflects primarily the environment, the faunal resources, and only secondarily an economic heritage" (Taylor 1966, p. 118).

Studies since then have confirmed 'whaling' and 'non-whaling' variants of Thule economy. This discrepancy in the apparent emphasis placed on bowheads may well prove, with additional research, to be more a gradation than a dichotomy. Currently, we know that bowheads were rarely used at western Canadian Arctic Thule sites of the Mackenzie Delta-Coronation Gulf region (Taylor 1966; McGhee 1975; Morrison 1983) and at sites along the continental margin (Savelle 1987). At the latter sites, seals and caribou were important in the diet, whereas bowheads were more frequently represented at central and eastern Canadian Arctic Archipelago sites. This difference in the relative importance of bowheads makes it nearly impossible to generalize about *all* Canadian Thule winter sites. The discussion presented here applies to the central and eastern sites where bowheads are typically found associated with winter house sites.

Despite the recognition of non-whaling variants of Thule subsistence, the bowhead whale is considered instrumental in Thule development. McGhee (1969/1970, 1972, 1975) and McCartney (1971, 1977), in particular, stressed the primacy of bowheads in the initial expansion of Thule Eskimo society out of Alaska about 1000 AD, and the subsequent 'decline' or 'transition' of Thule culture to historic Inuit cultures. Briefly, they related the development of a bowhead whaling industry in Alaska about 1000 AD and subsequent expansion across Canada and into Greenland with a warming trend (Neo-Atlantic period). This warming apparently resulted in a decrease in the extent and duration of summer sea ice cover, which in turn led to an increase in the abundance and distribution of bowhead whales. Conversely, the decline in whaling and abandonment of the High Arctic beginning about 1400 AD was equated with a cooling trend (Neo-Boreal period). That is, the cooling resulted in an increase in sea ice cover, which in turn resulted in a decrease in the abundance and distribution of bowheads and a shift in the Thule economy to alternate sea and land resources.

Subsequent studies by other researchers have tended to be based on and/or reinforce this general scenario (e.g. Dekin 1972; Schledermann 1975, 1979; Stanford 1976; Sabo 1981; Savelle 1987). However, McGhee (1983, p. 23; this volume) suggested that the early migration, at least, may well have been triggered by other causes, in particular the availability of meteoritic iron in northern Greenland, a suggestion also put forward by Blaylock (1980, p. 85) and McCartney (1982). Nevertheless, the standard practice until recently was to equate bowhead whale bone at a dwelling site with active bowhead whaling. This facile interpretation changed, however, with the publication of a critique by Freeman (1979) of Thule Eskimo whaling.

LIMITATIONS OF WHALING INTERPRETATIONS

The view of Thule as an active whaling culture, with the exception of Taylor's (1966) caveat, was not seriously questioned until Freeman (1977, 1979) suggested that arctic archaeologists had placed undue emphasis upon the presence of whale bone in Thule sites when interpreting Thule subsistence. That is, the "... distinction between a whale bone utilizing people and a whale hunting people does not appear to be explicitly recognized in the reconstructions advanced to date" (Freeman 1979, p. 279). Freeman presented several other related objections, but the whale bone use vs active whale hunting distinction was the most critical. While McCartney (1980A) has responded to these criticisms, Freeman's article focused the attention of archaeologists on the problems of the logical development from data to archaeological/ethnographic generalizations.

Consequently, arctic archaeologists have become much more cautious in their interpretations of whaling. For example, in discussing the faunal remains from the Learmonth site on Somerset Island, Taylor and McGhee (1979, p. 114) noted: "... we do not know how much of that food [represented in the houses and middens], if any, came from whales whose bones were found in a house." Staab (1979, p. 362), in discussing the faunal remains from the Silumiut site, concluded that "... food and raw material procurement primarily involved the hunting and processing of seal and caribou." Nevertheless, she added that "... were it possible to definitely establish the role of the great baleen whales in the [subsistence] economy, seals and caribou might be relegated to secondary importance."

Faunal material recovered by McCartney (1979A) from several sites on Somerset Island was analyzed by Rick (1980, p. 114), who suggested "... it is hard to assess the importance of whales to a particular house's economy ... since the whale bones in individual dwellings ... could have been collected by the Thule builders from abandoned houses and beached carcasses as well as from freshly killed whales." Accordingly, she excluded bowhead whales from her assessment of the contribution to the diet represented by the archaeofauna.

Morrison (1983, p. 224), while noting baleen in the recovered material from his excavations on Coronation Gulf, concluded that the "... importance of this species in Thule subsistence economies cannot be validly quantified ..." Thus, he excluded bowheads from a discussion of Thule subsistence in that region.

Finally, McGhee (1984, p. 81), despite recording a minimum of 20 bowhead whales represented at the Brooman Point site on Bathurst Island, asserted that the site "... provides little evidence of the importance of large whales in local subsistence."

A recent review of faunal (dietary) remains identified at Thule sites across the Arctic (Savelle and McCartney, in press) shows that by excluding whale bones from faunal analyses, 90% of the bones are of small seals, caribou, and foxes. Are we to assume that 90% of the Thule diet was based on these three kinds of animals? We have little alternative unless bowhead bones are evaluated and included as dietary evidence.

Clearly, if archaeologists are unable to determine past subsistence at the individual site level, then generalizations regarding subsistence for broad regions, whether explicit or implicit, must necessarily be very tenuous. We must have at least *some* knowledge of the nature and extent of subsistence and the role of whaling in it if we are to interpret other, non-subsistence aspects of Thule society, such as social, demographic, and ideological behaviour.

FUTURE RESEARCH DIRECTIONS

The major problem in Thule whaling studies is not lack of careful research or insufficient data. The studies noted above, for example, individually represent significant contributions in many areas of Thule archaeology. The main problem is that these studies have not been designed *specifically* to examine the question of Thule whaling; they have as a rule been site-specific studies, designed with other, primarily cultural-historical, questions in mind. Therefore, factors such as architectural vs diet-related whale bone, scavenged whale skeletons/carcasses vs hunted animals, and the 'schlepp' effect (wherein non-useful parts of large animals such as bones, unless utilized for building purposes, were left at the processing sites; see Daly 1969) cannot be adequately addressed through such studies.

In order for the problems of bowhead interpretation to be addressed adequately, two factors must be recognized. The first is that Thule subsistence strategies must not be regarded in isolation, but rather as articulating with other aspects of Thule culture. Traditional Thule studies have focused on one type site only, the winter residential site, with emphasis on settlement dates, house descriptions, artifact types, traded materials, and evidence of migrations. Historically, however, Inuit whaling was a complex activity that involved logistically organized groups operating over large areas and performing specialized tasks. As discussed by Binford (1980, 1982), such activities produce characteristic site types and characteristic site distributions. Thus, in order to fully investigate Thule whaling, the entire range of associated activities and sites must be examined. This, in turn, requires a *regional* as opposed to a site-specific approach.

A second factor that should be recognized is that quantification of fauna in *absolute* (nominal) terms suffers from a number of serious problems (e.g. Lyman 1982; Grayson 1984). Consequently, relative (ordinal) data are best employed in inspecting such aspects as faunal frequencies, abundances, and meat weights. When dealing with large fauna such as whales, where various parts have multiple uses (e.g. subsistence and architecture), even relative comparisons between these and other fauna are invalid. Accordingly, archaeological whale bone at one site/area can be compared with archaeological whale bone at other sites/areas, but cannot be directly compared with other faunal remains.

The following section summarizes the results of recent studies of Thule Eskimo whaling initiated by us and developed with the above two factors as guiding principles. We believe this approach can contribute to a better understanding of this aspect of arctic prehistory.

THULE ESKIMO WHALING ON SOMERSET ISLAND: AN EXAMPLE OF A REGIONAL APPROACH

The regional study described here examines Thule whaling from the perspective of predator-prey relationships. If examined through a series of archaeological expectations, this in turn allows us to determine predation (active hunting) from scavenging, and to determine the *relative* extent of whaling spatially and/or temporally. If Thule Eskimos in a region indeed actively hunted whales, then we should find evidence of:

(a) site types and site patterning indicative of active whaling, according to the presumed extent of active whaling;
(b) deliberate prey selection, and;
(c) bone distribution patterns indicative of active whaling.

There are additional archaeological correlates of active whaling, but these three will serve to demonstrate the value of a regional approach.

Site Types and Site Patterning

As an example of the relationships between hunter-gatherer site types, site patterning, and prey species, Binford (1980, 1982) defined two kinds of systems: collecting and foraging. Collecting systems are based on 'specialized' subsistence strategies which involve logically organized task groups intercepting specific, generally large and/or abundant prey animals. These animals result in large, storable surpluses. Such systems generate five site types:

(1) residential bases, which are the principal residential localities or settlements for social groups;
(2) locations, which are the principal places where resources are procured and, often, initially processed;
(3) stations, which are the principal places from which information on resources is gathered (e.g., observation points);
(4) field camps, which are temporary encampments for specialized task groups, such as whaling crews, and;
(5) caches, which are localities where various products are stockpiled, such as meat and blubber.

Binford also discussed the spatial arrangement of such sites, and suggested that the residential bases or settlements will tend to be at the centre of foraging zones of approximately 10 km radius and logistical zones of approximately 20 km radius. Foraging zones contain those sites relating to activities conducted on a regular basis and/or within a day's 'foraging' or walking, while logistical zones contain sites that are used by groups organized for temporary tasks, intercepting resources, and initially processing resources. Furthermore, Binford suggested that the movement of residential base sites will result, over time, in a sequential pattern of zone sets or groups of settlements, their stations, camps and caches (Figure 7). As Savelle (1987) has suggested, however, contemporaneous zone sets also reflect territoriality. That is, each local band's territory will be separated from adjacent bands' territories by the zone sets.

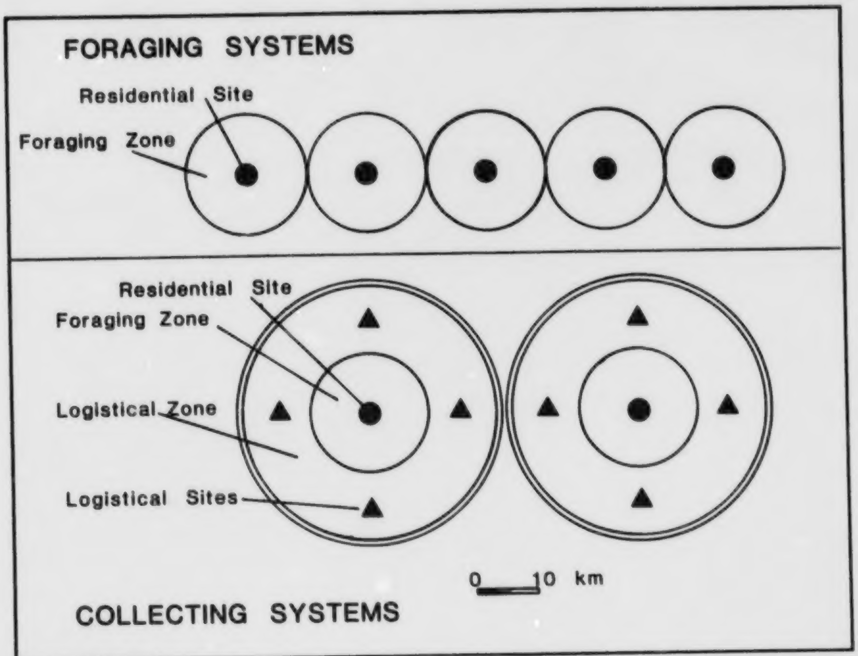


FIGURE 7: Idealized patterns of economic zones associated with: (a) foraging systems and (b) collecting systems. After Binford 1982.

The second type of system, the foraging system, is fundamentally different in that it is related to a generalized subsistence strategy. In this system, prey species tend to be harvested when encountered rather than when intentionally intercepted. Prey species tend to be smaller and/or less abundant and offer comparatively little surplus for storage. Such systems typically lack logistical zonation (Figure 7), and sites tend to be primarily residential bases and procurement locations.

The above systems are 'ideals' in that rarely will any hunter-gatherer society be either of the two extremes (e.g. Kelley 1983). However, active whaling societies, such as those of Thule Eskimos who whaled and created enormous surpluses, should exhibit collecting tendencies, while societies engaged in less, or no, active whaling should exhibit foraging tendencies (the !Kung San and Australian Aborigines are examples of foraging peoples).

In order to examine Thule society from the collecting vs foraging perspective, two areas on Somerset Island have been compared: Creswell Bay and Aston Bay (Figure 8). We have conducted detailed investigations here since 1975. Thule occupations at Creswell Bay have previously been demonstrated to be classic Thule, that is, relating to the period of maximum bowhead whale distribution and abundance (McCartney 1979A; Taylor and

McGhee 1979). The Thule occupation at Aston Bay, on the other hand, appears to be of a later period, when bowhead whales were becoming less abundant and more restricted in distribution (Savelle 1987). Neither Creswell Bay nor Aston Bay sites have been sufficiently radiocarbon dated, but we estimate that most of the Creswell Bay sites date to about 1200--1300 AD, while the Aston Bay sites date to about 1400-1500 AD. Furthermore, Aston Bay is near the western extreme for the eastern Arctic bowhead whale stocks, such that even if the occupations relate to the classic Thule period, they are nevertheless within an area where bowheads were probably less predictable and abundant.

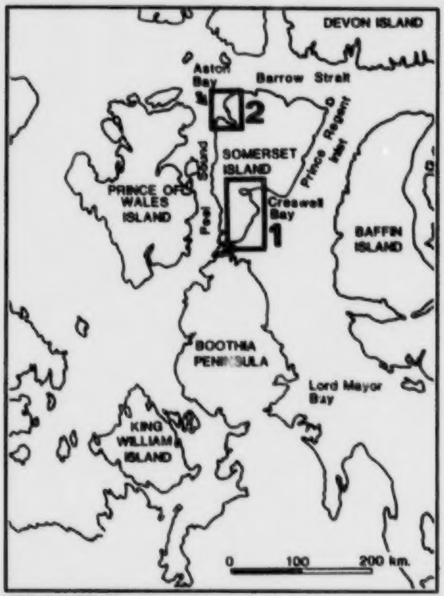


FIGURE 8: Survey regions in the study area: 1 - Creswell Bay; 2 - Aston Bay.

The distribution of various site types in these two areas are represented in Figures 9 and 10, and the relative frequencies are shown in Figure 11. For purposes of comparison, permanent residential bases are defined as half-buried winter house sites and temporary residential bases are those containing three or more summer tent rings or winter snow-houses. Locations are those sites or site components containing bowhead bones in non-dwelling contexts (for instance, whale beaching-butchering spots), and caches are sites of stone cairns or gravel depression features (Figure 6). Finally, field camps are those sites or site components containing one or two tent rings. The distinction between field camps and temporary residential sites is based on nineteenth century ethnographic literature suggesting that small task groups (male hunting crews, for example) overnighted in two or less tents (or igloos). Larger groups, such as three or more families camping at a river for fishing, represent temporary settlements in as many tents (Savelle 1987). Obviously, this is a fine archaeological distinction between two and three tent rings, and greater differences (for example, between two and six or more rings) would be more clearcut. No stations were identified, which is to be expected, given their low archaeological visibility (Binford 1978).

Dealing first with the relative frequencies of the different sites or component types, there is a clear contrast between the few logistically-related sites such as field camps and

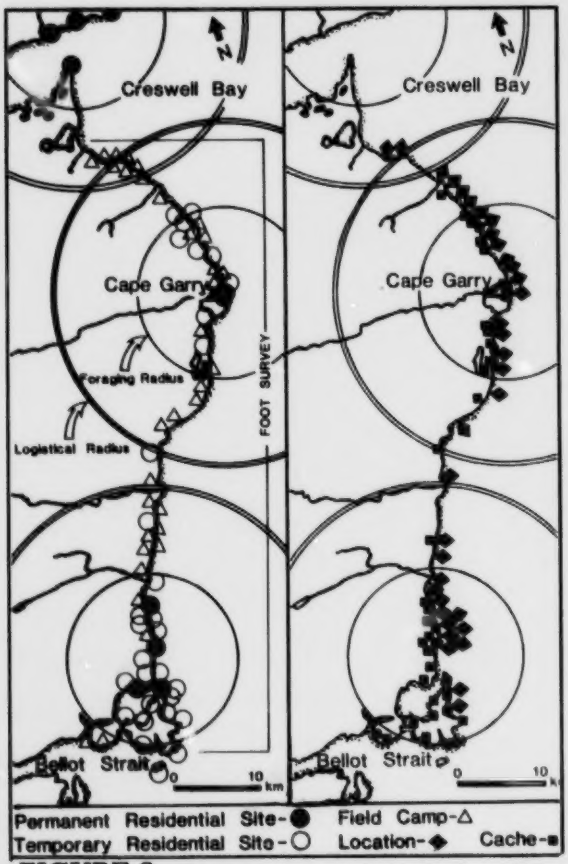

Creswell Bay
N
Cape Garry
Foraging Radius
Logistical Radius
FOOT SURVEY
Bellot Strait
0
10 km
Permanent Residential Site-●
Temporary Residential Site-○
Field Camp-△
Location-◆
Cache-▪

FIGURE 9: **Thule site characteristics in the Creswell Bay area, with foraging and logistical radii from major permanent residential site clusters indicated. From Savelle and McCartney (in press).**

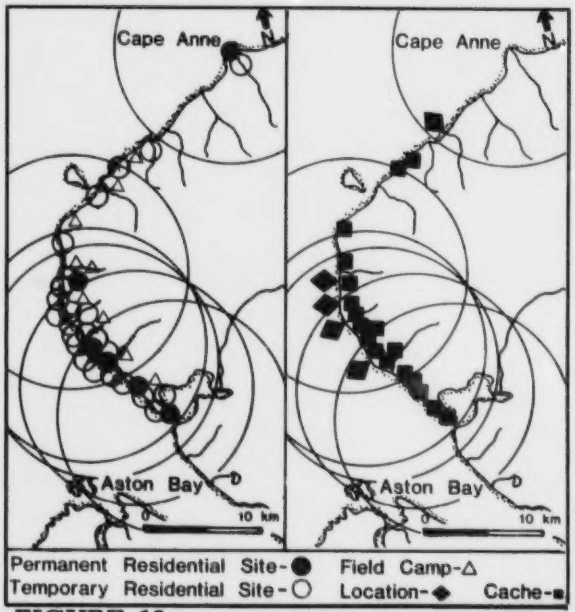

Cape Anne
N
Aston Bay
0
10 km
Permanent Residential Site-●
Temporary Residential Site-○
Field Camp-△
Location-◆
Cache-▪

FIGURE 10: **Thule site characteristics in the Aston Bay area, with foraging radii from major permanent residential site clusters indicated. From Savelle and McCartney (in press).**

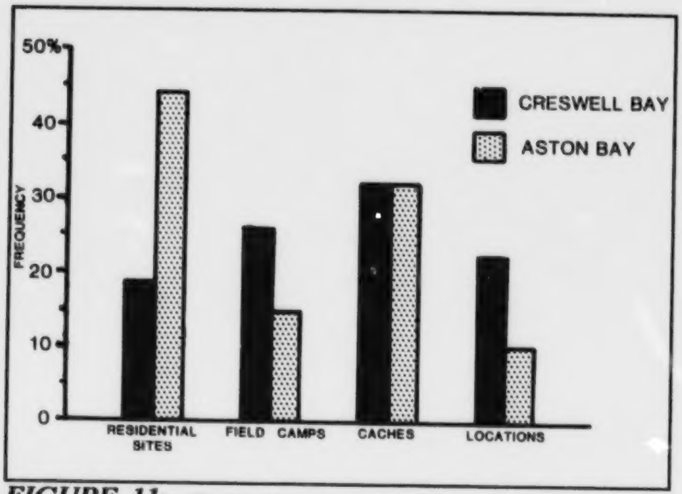


FIGURE 11: Site type frequencies at Creswell Bay and Aston Bay.

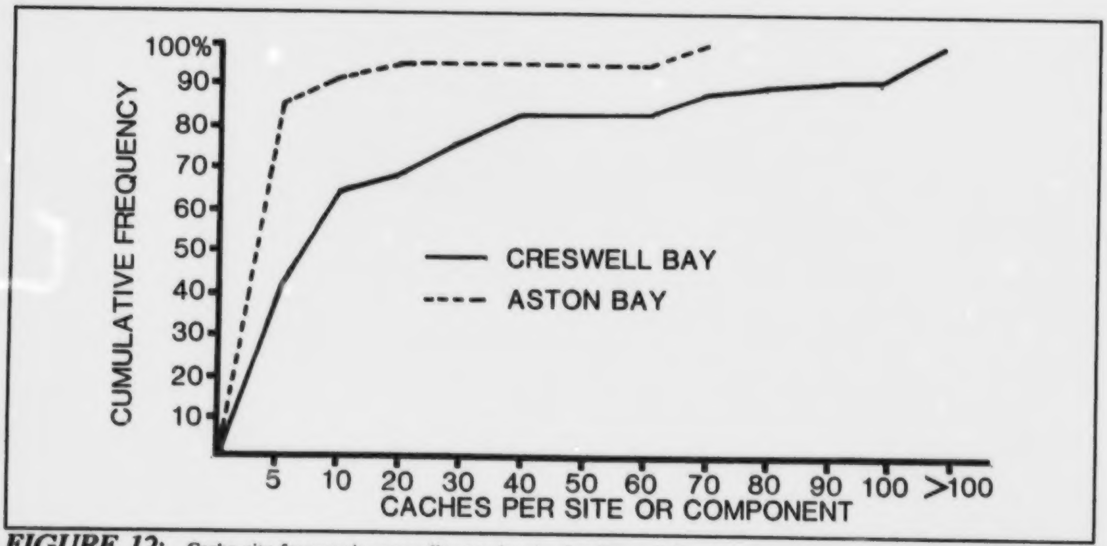


FIGURE 12: Cache site frequencies according to site size for Creswell Bay and Aston Bay. From Savelle and McCartney (in press).

locations (whale processing sites) at Aston Bay and the greater number of residential sites at Creswell Bay. Furthermore, although the relative proportions of cache sites or components are similar, there is a much greater frequency of large cache sites at Creswell Bay (Figure 12).

Looking now at zonation, in the Creswell Bay area major winter house settlements are concentrated in three regions: (1) to the south near Bellot Strait; (2) midway along the coast at Cape Garry; and (3) along the north coast of Creswell Bay (Figure 9). The three centres are separated by almost exactly two logistical radii (40 km). In addition, of the various sites or component types occurring within these zones, almost all temporary residential sites (large tent ring sites) occur within foraging zones, while almost all field camps (small tent ring sites) occur within logistical zones.

The pattern at Aston Bay, on the other hand, while displaying a separation of residential centres along the Aston Bay coast proper and Cape Anne, does not incorporate well-defined logistical zones. Instead, the permanent residential sites are more closely spaced than at Creswell Bay, primarily within overlapping zones (Figure 10). Essentially all other site types occur within these foraging zones.

According to the collecting vs foraging model, the prehistoric Thule society in the Creswell Bay area was logistically organized as a collecting system, which is appropriate to active whaling. Thule society at Aston Bay, on the other hand, was logistically organized as a foraging system, which is appropriate to less active whaling and more reliance on smaller animals.

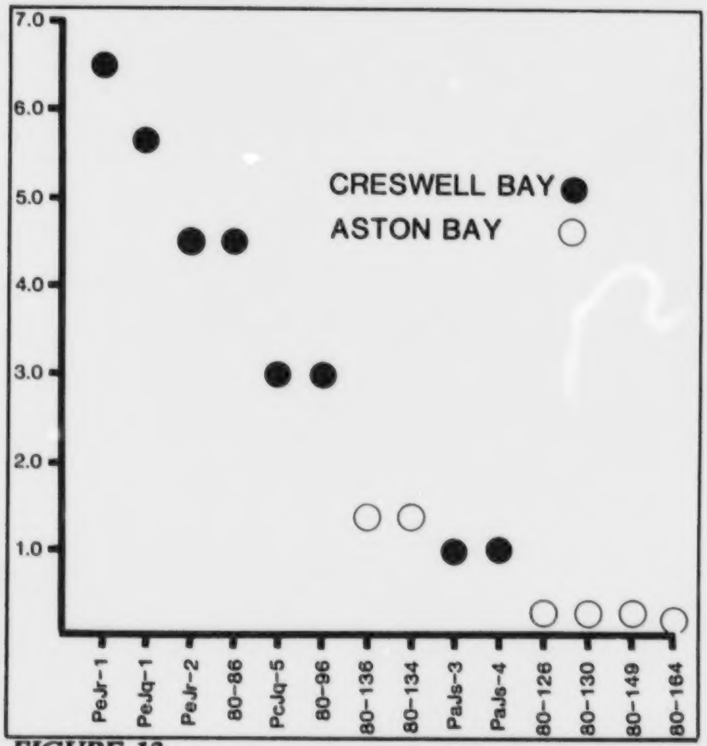


FIGURE 13: **Average minimum number of bowhead whales per dwelling at sites at Creswell Bay and Aston Bay. (Note that PeJr-2 is probably contemporaneous with the Aston Bay occupations). After Savelle and McCartney (in press).**

Finally, in support of the differences in the extent of whaling, we can compare the minimum numbers of bowheads represented at individual residential sites in the two areas. Assuming approximately similar occupation spans for the two areas (but not chronological periods; see Savelle 1987), the decrease in the importance of bowhead whales between Creswell Bay and Aston Bay is pronounced. This is indicated through the comparison of the average number of whales represented per dwelling (Figure 13).

Prey Selection

A second area of interest in determining active whaling vs whale scavenging is in prey selection. Specifically, if whale bone at Thule sites resulted from scavenging beached carcasses, then the demographic profile represented by whales at Thule sites should reflect the demographic profile of stranded whales.

Unfortunately, cetacean biologists know relatively little about bowhead whale stranding-patterns (Mitchell and Reeves 1982), but random strandings would be unlikely to affect only certain age-classes. On the other hand, ethnographic studies suggest that active whale hunters select certain age-classes, especially immature or small animals. During surveys of the Creswell bay area, McCartney (1978) measured 197 crania, 327 mandibles, 47 cervical vertebrae, and 110 scapulae of bowhead whales. Regression models based on Alaskan bowhead skeletons of approximate known whole animal size were applied to these bones and their original body lengths were estimated. Almost 97% of the bowheads represented are estimated to have been 7-10 m in length, which suggests they were immature whales (mostly yearlings but some two-year-old whales), since adult bowheads average greater than approximately 12 m (McCartney 1980B; Nerini *et al.* 1984).

Bone Distribution Patterns

Bone distribution patterns relate primarily to the question of active hunting vs scavenging. Specifically, if whale bone at archaeological sites was scavenged from beached carcasses or skeletons, then whale bone elements present at Thule dwelling sites should be correspondingly underrepresented at beach sites, while elements at the latter sites should be underrepresented at dwelling sites. Figure 14 compares the bowhead whale bone elements at the various beach sites where whale bones occur at Creswell Bay and Aston Bay and at two completely excavated half-buried dwellings at Creswell Bay. The element distribution is characteristic of a whale hunting as opposed to a whale bone scavenging pattern. That is, there is nothing approaching a 1:1 articulation of over-represented elements with underrepresented elements between beached bone sites and the half-buried dwellings. There is, however, considerably difference in relative abundance between mandibles and crania at the two residential sites. Much of this variation may be due to removal of whale bones by recent Inuit carvers (McCartney 1979A) or, at least for crania from PeJr-1, subsequent removal for garmang (temporary, shallow bone and skin dwellings) construction at nearby PeJr-2 (McCartney 1978).

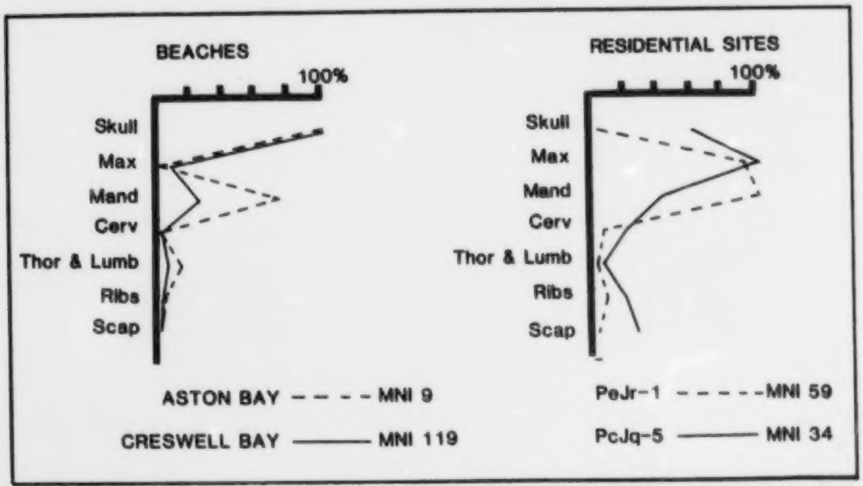


FIGURE 14: Bowhead whale element frequencies (as percent MNI) from semisubterranean dwelling sites and beach processing sites. From Savelle and McCartney (in press).

ARCHAEOLOGICAL WHALE BONES: THEIR RELEVANCE TO CETACEAN BIOLOGY

Whereas early historic accounts of Eskimo whaling are valuable, if often sketchy, testimony to the occurrence of native whaling, is rare. Ships' logs, whalers' journals, and Hudson's Bay Company records tell much about the frequency and range of bowheads (Ross 1974, 1979; Reeves *et al.* 1983). Archaeological whale bones add time depth and a material dimension to the diachronic study of bowhead stocks in the Canadian Arctic. Dated archaeological bone sites have been used by cetacean biologists to reconstruct past ranges, frequencies, and native predation of bowheads (Reeves and Mitchell 1985). Based on the assumption that heavy whale bones were used near the butchery locations where animals were beached, their distribution, frequency, and size can contribute to a better knowledge of the stocks before commercial whaling severely affected them. Because the modern Canadian bowhead stocks are relatively small compared to pre-commercial whaling numbers and have grown slowly since whaling ceased about 1915, archaeological whale bones spanning the earlier part of this millennium are valuable indicators of bowhead dynamics, including the relationship between ranges and fluctuating climatic episodes. Edward Mitchell (Arctic Biological Station, Quebec) and the second author began a study of archaeological whale bone measurements during the mid-1970s (McCartney 1980B), which is being expanded with the first author's participation.

FUTURE THULE WHALING RESEARCH

We have only begun to sample archaeological whale bones that may tell us much about bowhead procurement by prehistoric Eskimos, settlement patterns, as well as whale range and abundance. From studies of the King William Island-Boothia Peninsula-Somerset Island area, we believe that other Canadian Arctic areas could be profitably studied for similar and comparative data. Savelle (1987) has demonstrated the feasibility of foot surveys of shorelines to locate whale bones and associated features. By extending such surveys to other areas, we can better understand the variation that may exist in prehistoric use patterns and sizes of bowheads taken across the Canadian Arctic. A program of radiocarbon dating to provide better temporal control for Thule period whaling is crucial to future research.

Finally, more Inuit should be involved in studies of bowhead predation. Northern natives are familiar with bowheads (as they occur today) and maintain much oral tradition about past whaling. Whether anthropological and historical or biological and managerial, Inuit participation in all phases of bowhead studies can contribute significantly to a clearer knowledge of past use, as well as promoting future conservation.

ACKNOWLEDGEMENTS

The first author's research was supported by the Polar Continental Shelf Project, the Boreal Institute for Northern Studies, the Social Sciences and Humanities Research Council of Canada, the Science Advisory Board of the Northwest Territories, and the Arctic Institute of North America.

The second author's research was supported by the Archaeological Survey of Canada (Canadian Museum of Civilization), the Department of Indian and Northern Affairs, and the Polar Continental Shelf Project.

We are grateful to these institutions for their generous support.

Edward D. Mitchell (Arctic Biological Station, Quebec) has been of great assistance over the years in providing expertise on whales for our archaeological projects.

Figures 9, 10, 12, 13, and 14 are reproduced with the kind permission of Barry L. Isaac, editor, *Research in Economic Anthropology*.

REFERENCES

Binford, L.R. 1978. Dimensional analysis of behavior and site structure: learning from an Eskimo hunting stand. American Antiquity 43:330-361.

______. 1980. Willow smoke and dogs tails: hunter-gatherer settlement systems and archaeological site formation. American Antiquity 45:4-20.

______. 1982. The archaeology of place. Journal of Anthropological Archaeology 1:5-31.

Blaylock, S.K. 1980. A Thule bone and antler industry from Somerset Island, central Canadian Arctic. Unpublished M.A. thesis, Department of Anthropology, University of Arkansas.

Bockstoce, J. 1973. A prehistoric population change in the Bering Strait region. Polar Record 16(105):793-803.

______. 1976. On the development of whaling in the Western Thule Culture. Folk 18:41-46.

Collins, H.B. 1950. Excavations at Frobisher Bay, Baffin Island, Northwest Territories. National Museum of Canada, Bulletin 118:18-43.

______. 1951. Excavations at Thule Culture sites near Resolute, N.W.T. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 123:49-63.

______. 1952. Archaeological excavations at Resolute, Cornwallis Island, N.W.T. National Museum of Canada, Bulletin 126:48-63.

Collins, H.B. 1955. Excavations of Thule and Dorset Culture sites at Resolute, Cornwallis Island, N.W.T. National Museum of Canada, Bulletin 136:22-35.

Daly, P. 1969. Approaches to faunal analysis in archaeology. American Antiquity 34:146-153.

Dekin, A.A. 1972. Climatic change and cultural change: a correlative study from Eastern Arctic prehistory. Polar Notes 12:11-31.

______. 1978. Arctic archaeology: a bibliography and history. Garland Press, New York.

Freeman, M.M.R. 1977. A critical view of Thule Culture and ecological adaptation. Paper presented at the 10th Annual Meeting of the Canadian Archaeological Association (Ottawa, May 1977).

______. 1979. A critical view of Thule Culture and ecological adaptation. In: Thule Eskimo Culture: An Anthropological Retrospective. Edited by: A.P. McCartney. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 88:278-285.

Grayson, D.K. 1984. Quantitative zooarchaeology. Academic Press, New York.

Jenness, D. 1940. Prehistoric culture waves from Asia to America. Journal of the Washington Academy of Sciences 30:1-15.

Jochim, M.A. 1976. Hunter-gatherer subsistence and settlement. Academic Press, New York.

Kelley, R.L. 1983. Hunter-gatherer mobility strategies. Journal of Anthropological Research 39:277-306.

Larsen, H. and F.G. Rainey. 1948. Ipiutak and the Arctic Whale Hunting Culture. Anthropological Papers of the American Museum of Natural History 42.

Lowther, G.R. 1962. An account of an archaeological site on Cape Sparbo, Devon Island. National Museum of Canada, Bulletin 180:1-19.

Lyman, R.L. 1982. Archaeofaunas and subsistence studies. Advances in Archaeological Method and Theory 5:331-393.

Manning, T.H. 1956. Narrative of a second Defence Research Board expedition to Banks Island, with notes on the country and its history. Arctic 9:3-77.

Marquette, W.M. 1978. Bowhead whale. In: Marine Mammals of Eastern North Pacific and Arctic Waters. Edited by: D. Haley. Pacific Search Press. pp. 70-81.

Mathiassen, T. 1927A. Archaeology of the Central Eskimos: Part I. Descriptive. Report of the Fifth Thule Expedition, Volume 4, Copenhagan.

Mathiassen, T. 1927B. Archaeology of the Central Eskimos: Part II. The Thule Culture and its position within the Eskimo culture. Report of the Fifth Thule Expedition, Volume 4, Copenhagen.

Maxwell, M.S. 1983. A contemporary ethnography from the Thule period. Arctic Anthropology 20:79-87.

______. 1985. Prehistory of the Eastern Arctic. Academic Press, New York.

McCartney, A.P. 1971. Thule Eskimo prehistory along northwestern Hudson Bay. Ph.D. dissertation, Department of Anthropology, University of Wisconsin-Madison.

______. 1977. Thule Eskimo prehistory along northwestern Hudson Bay. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 70.

______. 1978. Study of whale bones for the reconstruction of Canadian arctic bowhead whale stocks and whale use by prehistoric Inuit. Report submitted to Northern Environmental Protection Branch, Indian and Northern Affairs Canada, Ottawa.

______. 1979A. Archaeological whale bone: a northern resource. University of Arkansas, Anthropological Papers 1.

______. 1979B. A processual consideration of Thule whale bone houses. In: Thule Eskimo Culture: An Anthropological Retrospective. Edited by: A.P. McCartney. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 88:301-323.

______. 1980A. The nature of Thule Eskimo whale use. Arctic 33:517-541.

______. 1980B. Study of archaeological whale bones for the reconstruction of Canadian Arctic bowhead whale stocks and whale use by prehistoric Inuit. Final report submitted to Northern Environmental Protection Branch, Indian and Northern Affairs Canada, Ottawa.

______. 1982. Re-evaluation of metal use by Thule Eskimos of the Canadian Arctic. Paper presented at the Annual Meeting of the Society for American Archaeology, Minneapolis.

McCartney, A.P. and J.M. Savelle. 1985. Thule Eskimo whaling in the central Canadian Arctic. Arctic Anthropology 22:37-58.

McGhee, R. 1969/1970. Speculations on climatic change and Thule Culture development. Folk 11/12:173-184.

______. 1972. Copper Eskimo prehistory. National Museum of Man, Publications in Archaeology 2. Ottawa.

______. 1975. An individual view of Canadian Eskimo prehistory. Canadian Archaeological Association, Bulletin 7:55-75.

McGhee, R. 1983. Eastern Arctic prehistory: the reality of a myth? Musk-Ox 33:21-25.

______. 1984. The Thule village at Brooman Point. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 125.

McVay, S. 1973. Stalking the arctic whale. American Scientist 61:24-37.

Mitchell, E.D. 1977. Initial population size of bowhead whale (*Balaena mysticetus*) stocks: cumulative catch estimates. Report of the International Whaling Commission 33:1-113.

Mitchell, E. and R.R. Reeves. 1982. Factors affecting abundance of bowhead whales *Balaena mysticetus* in the eastern Arctic of North America, 1915-1980. Biological Conservation 22:59-78.

Morrison, D.A. 1983. Thule culture in western Coronation Gulf, N.W.T. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 116.

Murdoch, J. 1892. Ethnological results of the Point Barrow Expedition. In: Ninth Annual Report of the Bureau of Ethnology (1887-88).

Nerini, M.K., H.W. Braham, W.M. Marquette, and D.J. Rugh. 1984. Life history of the bowhead whale, *Balaena mysticetus* (Mammalia: Cetacea). Journal of Zoology 204:443-468.

Oswalt, W.H. 1979. Eskimos and explorers. Chandler and Sharp Publishers, Novato, California.

Parry, W.E. 1824. Journal of a second voyage for the discovery of a Northwest Passage from the Atlantic to the Pacific; performed in the years 1821-22-23, in His Majesty's Ships *Fury* and *Hecla* under the orders of Captain William Edward Parry. John Murray, London.

Reeves, R.R. and E.D. Mitchell. 1985. Shore-based bowhead whaling in the eastern Beaufort Sea and Amundsen Gulf. Report of the International Whaling Commission 35:387-404.

Reeves, R.R., E.D. Mitchell, A. Mansfield, and M. McLaughlin. 1983. Distribution and migration of the bowhead whale, *Balaena mysticetus*, in the eastern North American Arctic. Arctic 36:5-64.

Rick, A.M. 1980. Non-cetacean vertebrate remains from two Thule winter houses on Somerset Island, N.W.T. Canadian Journal of Archaeology 4:99-117.

Ross, W.G. 1974. Distribution, migration, and depletion of bowhead whales in Hudson Bay, 1860 to 1915. Arctic and Alpine Research 6:85-98.

______. 1979. The annual catch of Greenland (bowhead) whales in waters north of Canada 1719-1915; a preliminary compilation. Arctic 32:91-121.

Sabo, G. 1981. Thule Culture adaptations on the south coast of Baffin Island, N.W.T. Ph.D. dissertation, Department of Anthropology, Michigan State University.

Savelle, J.M. 1980. An appraisal of Thule archaeology. M.A. thesis, Department of Anthropology, University of Arkansas.

______. 1987. Collectors and foragers: subsistence-settlement system change in the central Canadian Arctic, A.D. 1000-1960. British Archaeological Reports, International Series No. 358.

Savelle, J.M. and A.P. McCartney. (in press). Geographical and temporal variation in Thule Eskimo subsistence economies: a model. Research in Economic Anthropology 10.

Scammon, C.M. 1874. The marine mammals of the northwestern coast of North America. John H. Carmany and Company and G.P. Putnam's Sons, New York. (Reprinted by Dover Publications, New York, 1968).

Schledermann, P. 1975. Thule Eskimo prehistory of Cumberland Sound, Baffin Island, Canada. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 38.

______. 1979. the Baleen Period of the Arctic Whale Hunting Tradition. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 88:134-148.

Spencer, R.F. 1959. The North Alaskan Eskimo: a study in ecology and society. Bureau of American Ethnology, Bulletin 171.

Staab, M.L. 1979. Analysis of faunal material recovered from a Thule Eskimo site on the island of Silumiut, N.W.T. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 88:349-379.

Stanford, D.J. 1976. The Walakpa Site, Alaska. Smithsonian Contributions to Anthropology 20. Smithsonian Institution Press, Washington, D.C.

Taylor, W.E. 1963. Hypothesis on the origin of the Canadian Thule Culture. American Antiquity 28:456-464.

______. 1966. An archaeological perspective on Eskimo economy. Antiquity 40:114-120.

Taylor, W.E. and R. McGhee. 1979. Archaeological material from Creswell Bay, N.W.T., Canada. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper 85.

______. 1981. Deblicquy: a Thule Culture site on Bathurst Island, N.W.T., Canada. National Museum of Man Mercury Series, Archaeological Survey of Canada,, Paper 102.

ENVIRONMENTAL AND CULTURAL CHANGE IN THE LARGE LAKES REGION OF BAFFIN ISLAND: A PROGRESS REPORT

J.D. Jacobs[1], D.R. Stenton[2], and W.N. Mode[3]

Abstract: The interior of south-central Baffin Island in the vicinity of the large lakes, Nettilling and Amadjuak, is an unusually productive ecosystem in a landscape of abundant glacial and marine deposits and relatively warm summer climate. Located at the northern extremity of the Low Arctic bioclimatic zone, the region is an important range for caribou, and figures prominently in the nearly 4,000-year record of human occupation of Baffin Island. Preliminary results of paleoenvironmental and archaeological investigations suggest a mid-Holocene maximum of vegetation development and tundra productivity, with a significant presence of Pre-Dorset Culture people. A transition to a cooler, drier climate around 3,000 years ago made the area less habitable, but in the subsequent millennium the more arctic adapted Dorset Culture people used the area at least occasionally. During the last 700 or more years, the region became an important element in the annual settlement subsistence cycle of the Thule Culture, with year-round occupation occurring in some periods. This pattern of land-use persisted with the Inuit of southern Baffin Island into the present century, until transformed by the disruptive influence of sustained Euro-American contact.

Résumé: L'intérieur du centre-sud de l'île de Baffin à proximité des grands lacs de Nettilling et Amadjuak, est un écosystème remarquablement productif dans un paysage d'abondants dépôts glaciaires et maritimes et dans un climat relativement clément. Situé à l'extrémité nord de la zone bioclimatique du Bas-Arctique, cette région est très fréquentée par les caribous et constitue un élément dominant dans l'histoire de l'occupation de l'île de Baffin par les humains, depuis presque 4,000 ans. Les résultats préliminaires d'études archéologiques et paléoenvironnementales semblent indiquer un maximum de développement de la végétation et de la productivité de la toundra vers le milieu de l'Holocène, avec une présence marquée de peuples de culture pré-Dorset. Le climat étant devenu plus frais et plus sec, il y a environ 3,000 ans, la région s'est montrée moins habitable, mais, dans le millénaire suivant, les peuples de culture Dorset mieux adaptés à l'Arctique l'ont fréquentée au moins à l'occasion. Dans les 700 dernières années ou plus, cette région est devenue un élément important du cycle annuel d'établissement et de subsistance de la culture de Thulé et, à certaines périodes, a été occupée toute l'année. Ce modèle d'utilisation du territoire s'est poursuivi avec les Inuit du sud de l'île de Baffin jusqu'au siècle actuel, en fait jusqu'à sa transformation sous l'influence perturbatrice du contact régulier avec les Euro-Américains.

INTRODUCTION

Baffin Island, with an area of about 500,000 km^2, is the largest of the Canadian Arctic Islands. Spanning 12° of latitude and bioclimatic zones from Low Arctic to High, the island contains examples of nearly every arctic landscape and habitat type. A predominately Inuit population is distributed around the island in coastal settlements and outpost camps, and there is a distinctly maritime orientation to the traditional economy. The vast interior of the island is nonetheless important, particularly as range for barren-ground caribou (*Rangifer tarandus groenlandicus*).

Ethnographic accounts of late summer and autumn caribou hunting trips far inland are readily confirmed by Inuit elders. This testimony indicates more than just seasonal use of

---

[1] Department of Geography, University of Windsor, Windsor, Ontario N9B 3P4. Present address: Department of Geography, Memorial University of Newfoundland, St. Johns, Newfoundland A1B 3X9.
[2] Department of Anthropology, University of Alberta, Edmonton, Alberta T6G 2H4
[3] Department of Geology, University of Wisconsin, Oshkosh, Wisconsin 54901, U.S.A.

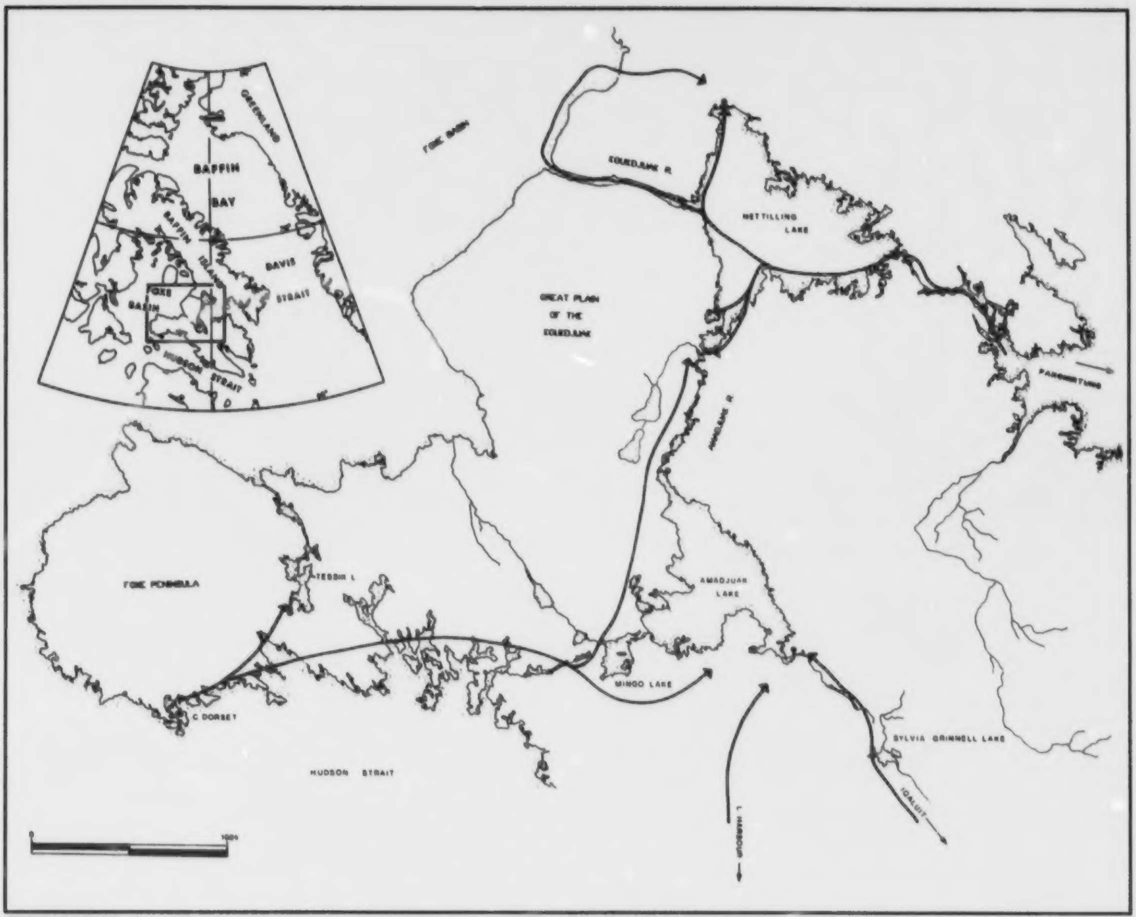

GREENLAND
BAFFIN
BAY
BAFFIN ISLAND
DAVIS
STRAIT
FOXE
BASIN
HUDSON STRAIT
FOXE BASIN
KOUKDJUAK R.
NETTILLING
LAKE
GREAT PLAIN
OF THE
KOUKDJUAK
AMADJUAK R.
PANGNIRTUNG
FOXE PENINSULA
TESSIK L
AMADJUAK
LAKE
MINGO LAKE
C DORSET
HUDSON STRAIT
SYLVIA GRINNELL LAKE
IQALUIT
L HARBOUR
0
100K

FIGURE 1: **The large lakes region of Baffin Island, showing traditional Inuit travel routes between the coastal settlement areas and the interior.**

the interior, however, in that there are also accounts of year-round occupation, an unusual practice by eastern Canadian Inuit standards. The particular region involved here is the south-central part of the island which contains the two large lakes, Amadjuak and Nettilling (Figure 1). Franz Boas (1888, p. 430) published Inuit accounts of both summer use near, and winter settlements on, Nettilling Lake in the nineteenth century, and a Royal Canadian Mounted Police report of the 1940s refers to possibly as many as 15 families occupying several camps around the lake for at least a year (McLauchlan 1944).

Such accounts imply that this interior region was a locally productive one and that southern Baffin Island Inuit were uniquely adapted to these circumstances. Given what is generally known of the impacts that fluctuations in climate may have on traditional kinds of Inuit economies, we hypothesized that this interior location would be a marginal one and thus a good locale in which to develop and test climate-impact models and theories of human adjustments to changing resources.

In 1984, we began a study of the physical environment and archaeology of what we call the large lakes region of Baffin Island (Figure 1). This initiative was a logical step following our work in coastal areas, particularly around Frobisher Bay, where a complicated picture of late- and postglacial climate and vegetational succession has emerged (Jacobs *et al.* 1985A), and where archaeological work (Stenton 1983) revealed the importance of interior caribou to the prehistoric people of the coastal region (Stenton 1983, 1987; Jacobs and Stenton 1985). Thus, a program was planned to detail the archaeological and paleoenvironmental records and to understand their relationship.

Four field seasons have provided us with a wealth of data, much of which remains to be analyzed, and there is much more field work to do. Here we present our preliminary findings and the conceptual framework that guides the work.

LANDSCAPE

The interior of south-central Baffin Island consists of low, glaciated granitic hills of the Precambrian Shield, flanked on the west by mainly flat, drift-covered Paleozoic limestone of the Foxe Lowland. Deglaciation of the lakes occurred sometime between 7,000 and 5,000 years ago, with the last remnants of the south Baffin Ice Dome east of Amadjuak Lake vanishing soon thereafter (Blake 1966). Inundation by the sea to an elevation of about 100 m above present sea level occurred during deglaciation, with subsequent emergence due to isostatic recovery. These events produced several kinds of surface features of particular significance in this study: (1) extensive sediments in the lowlands, including marine silt, which is a good substrate for vegetation development; (2) a complex drainage system of rivers, lakes and ponds; and (3) extensive linear features (moraines, eskers, and beach ridges) that stand above the wet lowlands (Figure 2). Thus, the legacy of the glacial and sea-level history includes relatively rich and varied habitats, as well as natural highways between them.

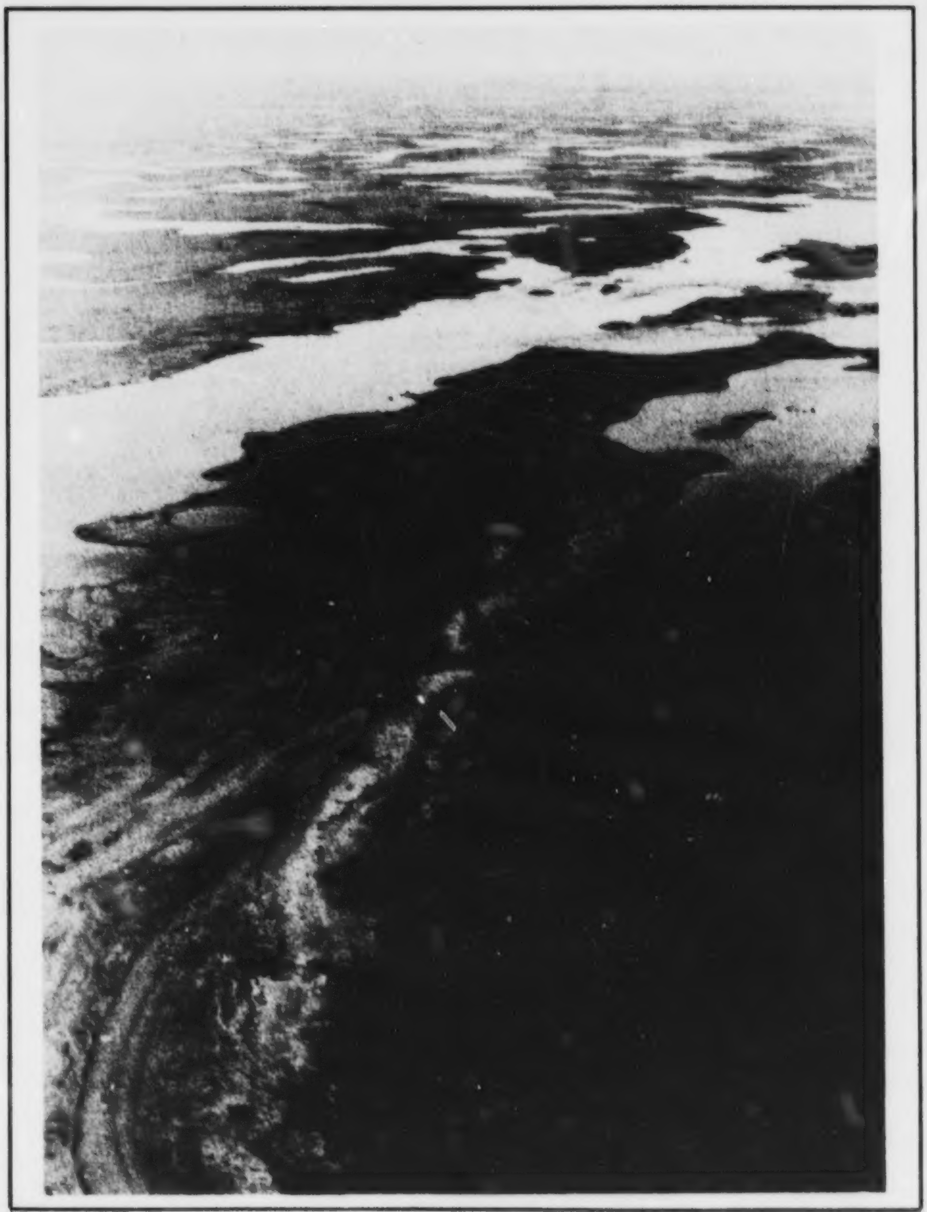


FIGURE 2: **Major washed moraine at the mouth of the Amadjuak River, looking eastward. This feature, an important caribou highway and river-crossing, has the largest concentration of archaeological features so far reported in the region.**

BIOGEOGRAPHY

The interior lowlands lie mostly within the Low Arctic bioclimatic zone as described by Porsild (1958), among others (see Bliss, and Edlund, this volume). Northeast and southeast of the lakes are areas of granite-gneiss bedrock with tundra-heath vegetation. Limestone areas to the west support a sparse cover dominated by mountain avens (*Dryas integrifolia*) and purple saxifrage (*Saxifraga oppositifolia*). Vast wetlands forming the Great Plain of the Koukdjuak extend westward from Nettilling Lake to Foxe Basin. This is a nesting area for many bird species, notably the Snow Goose (*Chen caerulescens caerulescens*). Arctic char (*Salvelinus alpinus*) are abundant in lakes and rivers, and a freshwater population of ringed seals (*Phoca hispida*) inhabits Nettilling Lake. The entire region is a summer range for caribou.

The warm summer climate suggested in regional climate maps (Maxwell 1980) has been confirmed by our field observations. Not surprisingly, we have found populations of several Low Arctic indicator species, such as dwarf birch (*Betula glandulosa*) and alpine azalea (*Loiseleuria procumbens*), well beyond their previously reported limits. Shrub-tundra characteristic of the Low Arctic bioclimate, is limited to areas underlain by acidic crystalline rock that are favourable because of moisture supply, protection from wind, and southerly exposure. Quantitative vegetation surveys have been carried out in an attempt to describe these patterns.

Surface pollen samples (moss and lichen polsters) have been collected around the western and southern ends of Nettilling Lake and on the south side of Amadjuak Lake. These are being analyzed and related to the presence or absence at the collection site of such indicator species as *Betula glandulosa*. Near Frobisher Bay, a statistically-significant difference in *Betula* pollen percentage was found between samples taken at sites where shrub-birch was present and those from sites with no birch (Jacobs *et al.* 1985B). Preliminary results show a similar relationship in Nettilling Lake samples, but with somewhat lower percentages. These results enable paleoecological interpretation of the fossil pollen record because they define a threshold *Betula* percentage which distinguishes Low Arctic from High Arctic bioclimates.

CLIMATOLOGY

The inland location, some 100 km from the icy waters of Foxe Basin, and low elevation contribute to a warm summer climate. The lakes, with their large thermal capacity, also play an important role in moderating the local climate, particularly in late summer and autumn. Our data from the Burwash Bay area, at the extreme southern end of Nettilling Lake, suggest a long-term average July temperature of about 9°C (Jacobs and Grondin 1988). Summer precipitation is light, with July totals at Burwash Bay of 23 mm in 1985 and 9 mm in 1986. Winds in summer are variable, but frequently from the south, and average about 5 m s^{-1}. Clear to partly cloudy days are not uncommon and solar radiation is consequently high, an average daily flux of 19.6 MJ m^{-2} d^{-1} having been recorded in July of 1986 (Jacobs and Grondin 1988). Observations in the region over four summers point to a large year-to-year variability in weather, as is generally the rule in the eastern Arctic.

A more complete climatic picture will result from installation of automatic stations at two places during the summer of 1987 (Figure 3). These instruments operate year-round on 3-hourly and daily programs to record standard climatic readings, as well as solar radiation and ground temperatures. The results will be used in developing a mesocale climate model that will have application in calibrating the fossil pollen record and in determining the local responses to regional changes in climate.

PALEOENVIRONMENTS

The principal method of determining past regional environmental conditions is through the stratigraphic analysis of fossil pollen in sediments. Past climate can then be inferred from relative abundances of various plant taxa in the pollen record, on the assumption (not always valid) that present climate-vegetation-pollen relationships apply to the past. With few exceptions, paleoclimatic reconstructions in the eastern Canadian Arctic have been based on fossil pollen sequences in terrestric peats, and have shown considerable disagreement across the region (Short *et al.* 1985). By contrast, we have found good stratigraphic

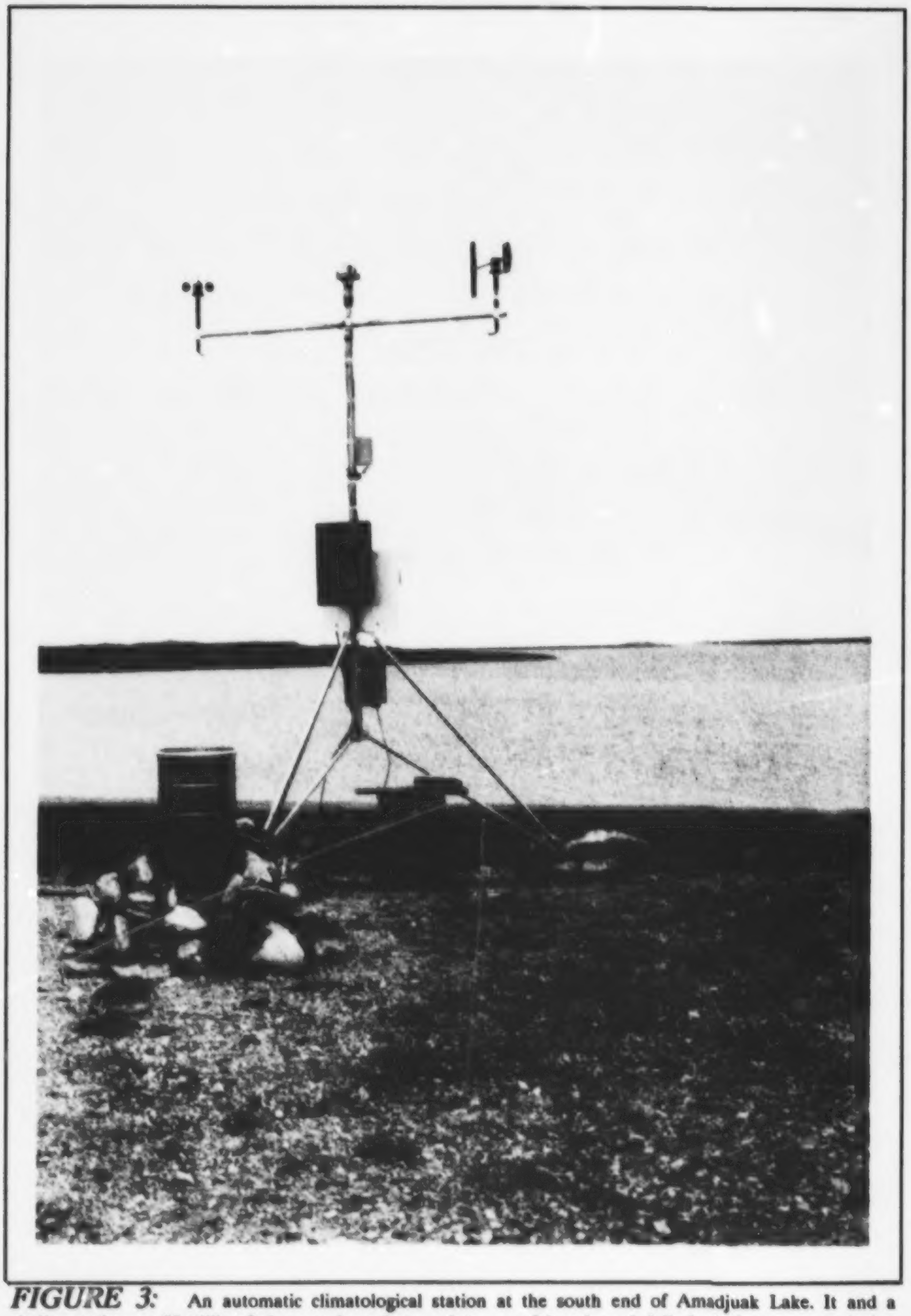


FIGURE 3: An automatic climatological station at the south end of Amadjuak Lake. It and a similar station on Nettilling Lake sample and store data on a 3-hourly and daily basis for recovery during the following summer.

agreement between a lake sediment core taken from Hikwa Lake[1] on Frobisher Bay (Mode and Jacobs 1985) and one described by Davis (1980) from Iglutalik Lake, near Pangnirtung.

Lake sediment cores were taken in Burwash Bay (Nettilling Lake) in 1986 and from South Bay (Amadjuak Lake) in 1987. Analysis has begun on the first, a 1 m-long core spanning the past 5,000 years. We expect the Nettilling and Amadjuak lake cores to confirm our interpretation of the general regional pattern, while showing special interior influences. This will be an important addition to the Holocene record for the eastern Arctic.

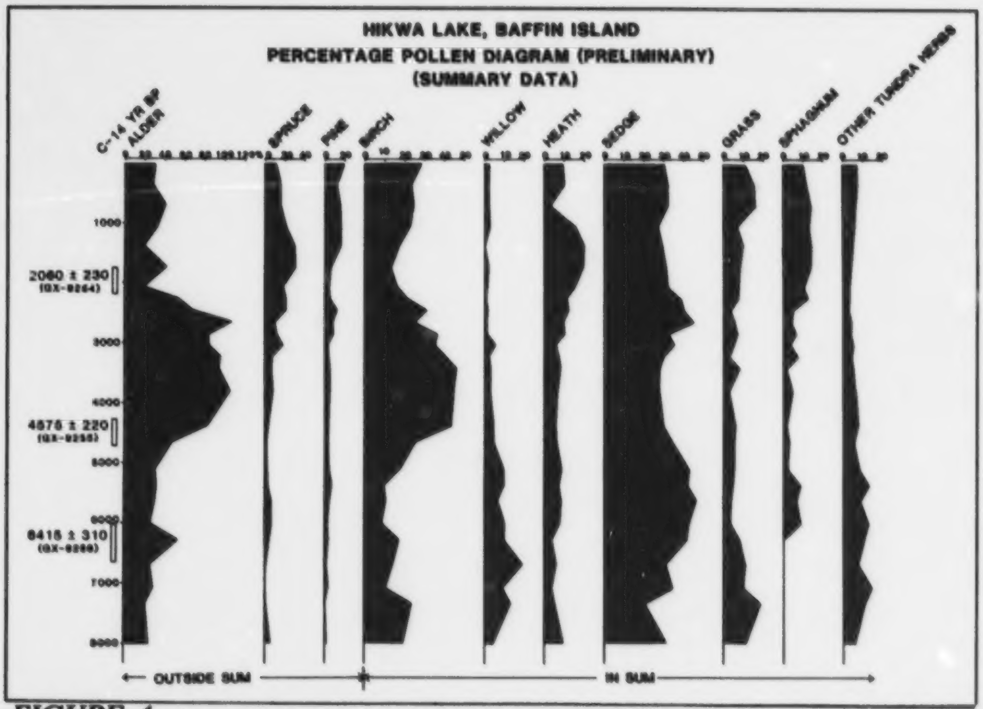


FIGURE 4: Percentage pollen diagram from Hikwa Lake on Frobisher Bay. Cores taken from Nettilling and Amadjauk lakes are expected to yield similar pollen records with some differences intrinsic to the interior region.

Pending those results, we can summarize what the Hikwa Lake record (Figure 4) tells us about developments in southern Baffin Island, and suggest how these apply to the large lakes region. Apparently Low Arctic vegetational elements (e.g. *Betula*) were present in a predominantly herbaceous tundra around the glacier margins of southern Baffin Island before

---

[1] Hikwa Lake is the unofficial name for a small (425 m x 150 m) lake located in Ward Inlet, on the north side of Frobisher Bay (63.5°N, 67.6°W).

7,000 yr B.P. Expansion of vegetation and a transition to shrub-tundra, at least in lower elevations, coincided with deglaciation. This trend reached its climax around 3,500 yr B.P., and subsequently shrub-tundra became more restricted, although a recovery may have begun in this century.

The Burwash Bay core consists of an algal gyttja containing scattered moss macrofossils that become more abundant with depth. Radiocarbon dates from two levels are: 2,825 ± 230 yr B.P. (S-2879) at 35 cm and 4,290 ± 315 yr B.P. (S-2878) at 85 cm. Extrapolation from the latter date shows that deglaciation occurred before 6,000 yr B.P. and was followed by a period of relatively rapid sedimentation and plant production that peaked between 4,000 yr B.P. and 3,500 yr B.P. Thereafter, the sedimentation rate decreased to less than half the earlier rate, and organic production declined. So perhaps a rather warm, wet climate prevailed soon after deglaciation and lasted until after 3,000 yr B.P., when climate rapidly became colder and drier. In outline, this is consistent with the record of the Hikwa Lake core. It remains now to determine through pollen analysis whether the shrub-tundra maximum and associated maximum of tundra primary productivity occurred simultaneously in both areas. Even more exciting is the prospect of being able to ascertain, with a resolution of a century or better, the sequence of changes that occurred in what during the mid-Holocene must have been a decidedly different environment from the present.

ARCHAEOLOGY

Two main cultural traditions are recognized in the prehistory of Arctic Canada: Paleo-Eskimo and Neo-Eskimo. The origins of both traditions, which collectively span some 4,000 years, have been traced to Alaska, from which a series of eastward migrations have occurred (see McGhee, this volume). These peoples were widely dispersed throughout the Arctic Islands and mainland where they adapted to various tundra and boreal forest environments (Maxwell 1985).

The Paleo-Eskimo tradition dates between about 4,000 and 900 yr B.P., and includes several temporal and/or regional variants (e.g. Independence I, Pre-Dorset, Dorset). Archaeological evidence from Independence I and Pre-Dorset sites indicates a greater reliance on terrestrial resources such as caribou and muskox than appears in the later Dorset period (about 2,800 - 900 yr B.P.). In the latter case, a stronger commitment to the maritime environment is seen as an adaptive response to climatic cooling and is reflected in the appearance of such items as snow-knives, sled-shoes, stone cooking vessels and ice creepers, used in procurement of marine mammals at the floe-edge or in open leads.

The second major tradition (Neo-Eskimo) developed in northern Alaska and appeared in the Canadian Arctic about 1,000 AD. Through processes that are not completely clear, these latest arrivals (the Thule Culture) supplanted the existing Dorset Culture. A primary distinction between the Thule and their Dorset predecessors was the ability of the former to harvest large baleen whales with a complex technological and social arsenal (cf. Minc 1986; Savelle and McCartney, this volume). An emphasis on hunting large whales may have developed as a response to their increased availability through an expansion of habitat during the warm Neo-Atlantic climatic episode (McGhee 1969/1970). Thule people were equally adept, however, at harvesting smaller marine mammals as well as other aquatic and terrestrial resources. The pronounced flexibility of their socio-economic system played a central role in their cultural development when the economic importance of large whale hunting diminished.

The archaeological part of our research focuses primarily on Thule land-use patterns. Traditionally, analyses of Thule socio-economic systems have been restricted to the coastal-winter dimension, and to correlating group behaviour with changes in climate and the ecology of certain marine resources. This approach has clearly established the central role of the maritime economy in Thule cultural development. However, it was not of exclusive importance, and its continued domination of Thule research is based primarily on a priori assumptions regarding the scarce inland archaeological record. As a result, we lack detailed information on the forms of inland adaptations, especially those surrounding caribou use. Despite recognition of this species as a critical subsistence resource during the pre-contact era, and its potential for dramatic fluctuations through time, little information is available beyond descriptions of caribou procurement methods and archaeological data on frequencies of caribou and bird remains.

Archaeological investigation of the large lakes region was prompted by Inuit oral traditions and ethnographic accounts that cite its importance to the seasonal round of three regional populations in southern Baffin Island (Figure 1) and by the demonstrated importance of caribou in coastal Thule winter settlement sites in upper Frobisher Bay (Stenton 1983, 1987; Jacobs and Stenton 1985). These sites are far from the resource-rich floe-edge in winter, and good local availability of caribou has been advanced as an argument for continued occupation of the upper bay region until the early contact period. The primary catalyst for travel to the interior was a need for caribou skins for winter clothing. But it is also clear that maintenance of social relationships through various forms of interaction (e.g. marriage, trade partnerships) also guided such behaviour (Boas 1888, pp. 15, 54-62).

Prior to this study, there had been no archaeological surveys in the interior lowlands, although travellers such as Hantzsch in 1910 (Millward 1930; Neatby 1977) and Soper in 1925 (Soper 1981, p. 60) reported finding cultural features on the lake shores. We conducted surveys along the northwest shore of Nettilling Lake and at its south end, as well as at the south end of Amadjuak Lake. Nearly 100 habitation sites have thus far been described (Stenton 1987), most of them in Burwash and Tikera bays of Nettilling Lake. With few exceptions, these sites are associated with prominent esker/moraine systems which provide good views of the surrounding area, some relief from swarms of mosquitoes and, because caribou travel along these features in the course of their movements around the lakes, the opportunity to intercept them at predetermined strategic locations such as river crossings (Figure 2).

The oldest site discovered so far is "Sandy Point" (L1Dv-10) on Burwash Bay (Figure 5), which is more than 3,000 years old, based on a radiocarbon date of 2,815 ± 65 yr B.P. (S-2780) from a buried soil overlying the cultural layers. Typing of lithic artifacts indicates that it represents an early to middle Pre-Dorset occupation (Figure 6) (Stenton 1986). Another productive site is L1Dv-4 near the mouth of Amadjuak River, which typologically is in the late Dorset cultural phase of about 1,000 to 1,100 yr B.P. Pre-Dorset and Dorset artifacts have been found at other sites too, so there is little doubt that this region was frequently inhabitated in the Paleo-Eskimo period.

The Thule Culture is represented at many sites on Nettilling and Amadjuak lakes. One of the largest is on the washed moraine complex at the mouth of Amadjuak River (Figure 2), where more than 150 features of various types (Figure 7) and artifact assemblages (Figure 8) attest to an economy based mainly on caribou, but using abundant fishes, waterfowl, and other resources. At other sites tangible evidence in the form of Thule-style winter half-buried (semi-subterranean) dwellings confirms early reports of occasional year-round settlements on the lakes (Figure 9).

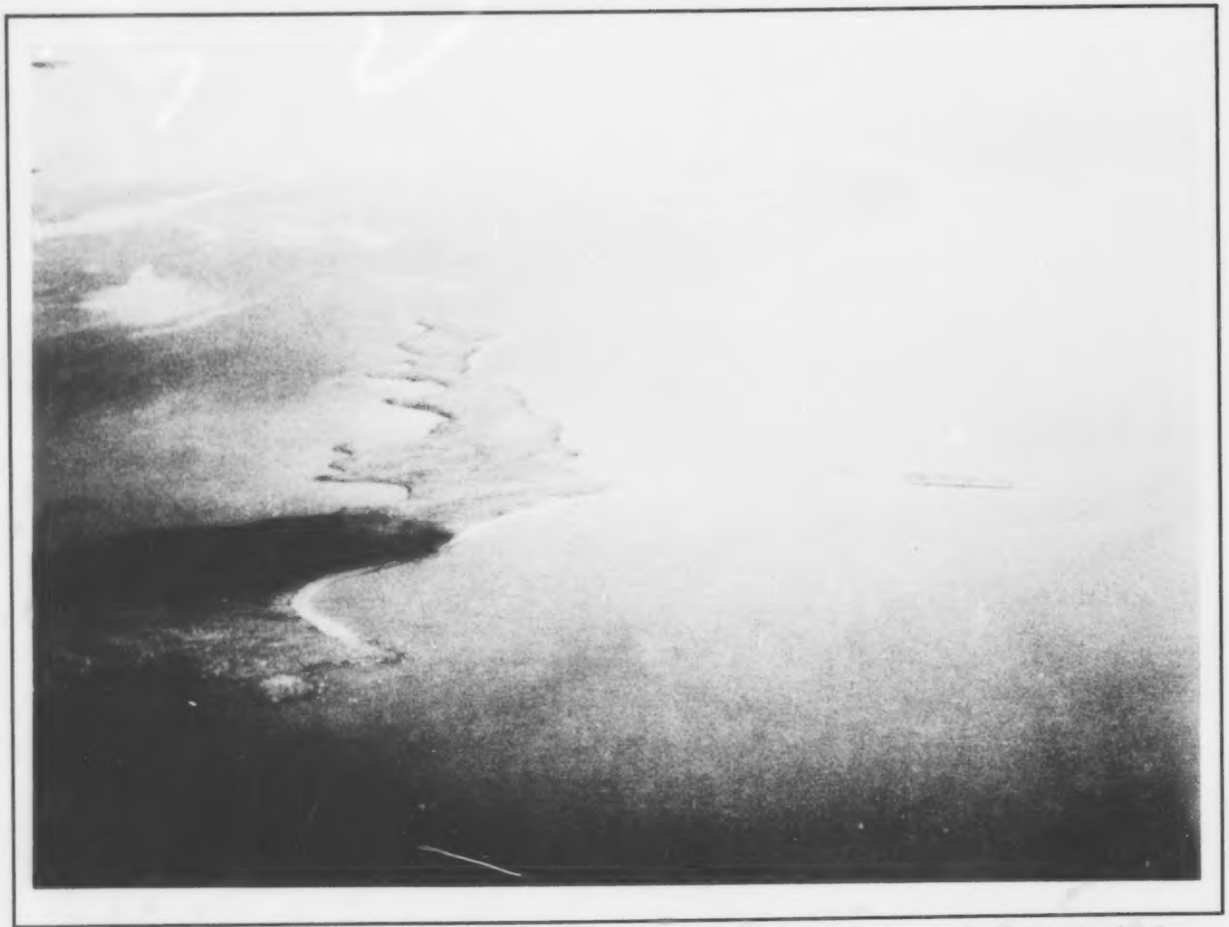


FIGURE 5: Aerial view of "Sandy Point" on Burwash Bay, Nettilling Lake. This is the location of a Pre-Dorset occupation that is at least 3,000 years old. Most of the site has eroded into the lake, but artifacts have been recovered *in situ* in the banks of the small island to the right, on the beach, and from the water.

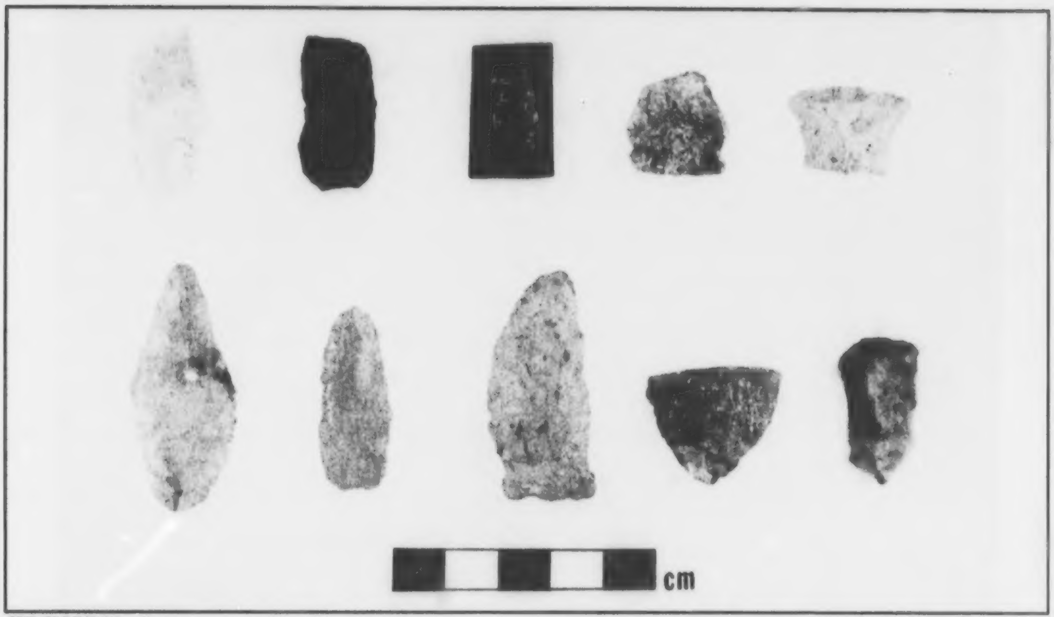


FIGURE 6: Selected Pre-Dorset artifacts from the "Sandy Point" site, including burins, end-blades, knives, and scrapers.

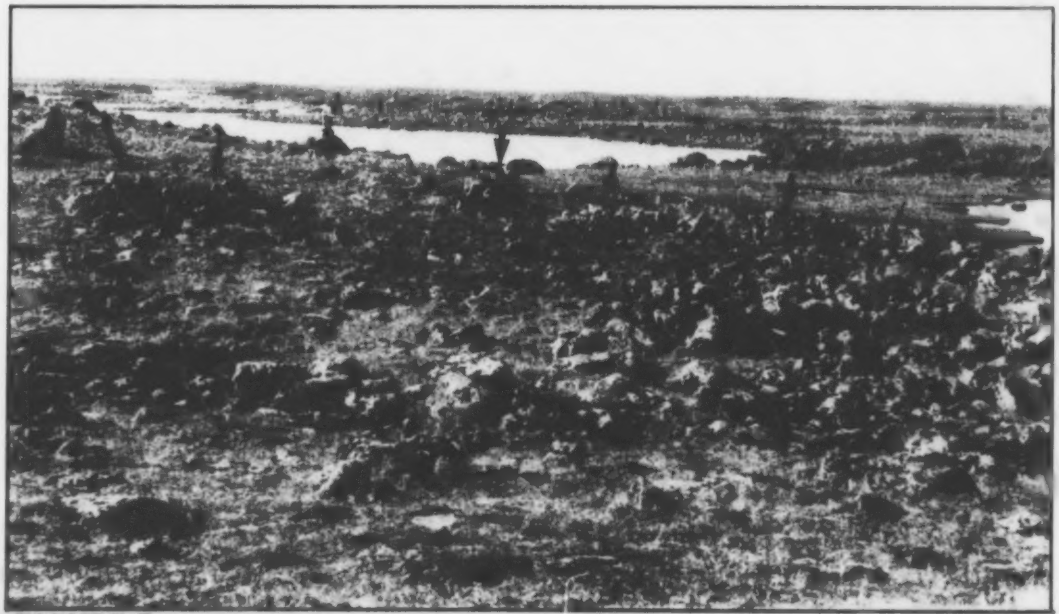


FIGURE 7: Concentration of caches, tent-rings and cairns on the crest of a moraine at the Amadjuak River mouth. They indicate intensive and repeated occupation of this site which overlooks a major caribou-crossing point.

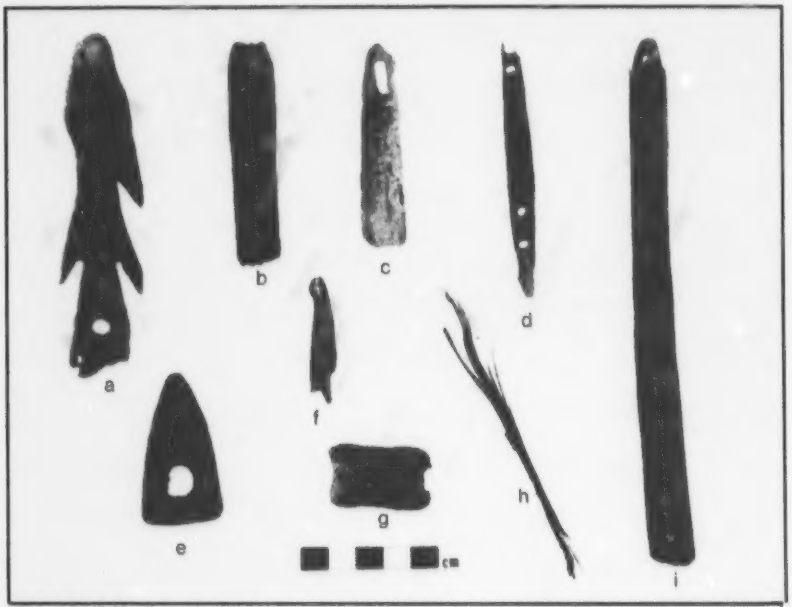


FIGURE 8: Thule Culture artifacts from the Burwash Bay area include: a sealing harpoon head (a), leister barbs (b,f), a dog trace buckle (e), a bow-drill mouthpiece (g), and a lance head (i) that are indicative of the range of subsistence activities. The harpoon head is common to Thule assemblages dating between about 1300 and 1600 AD.

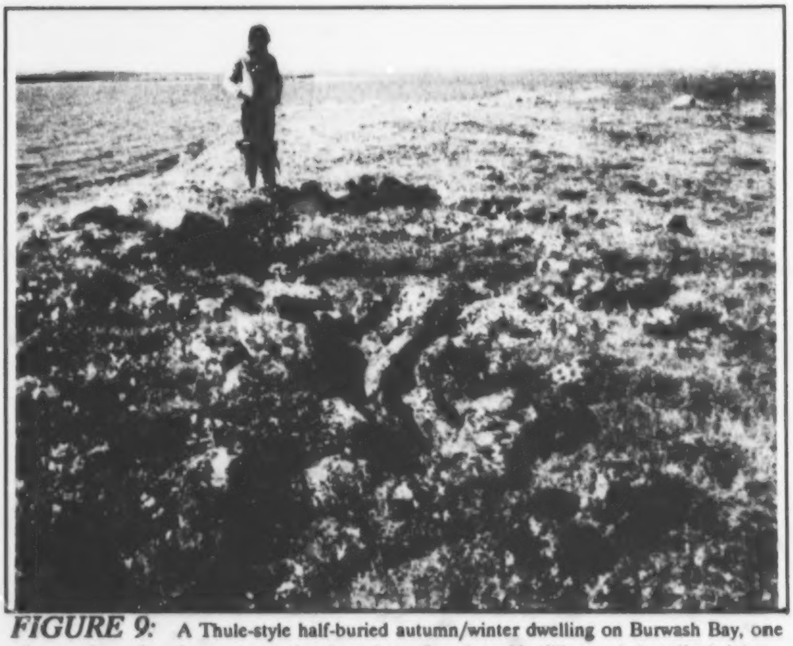


FIGURE 9: A Thule-style half-buried autumn/winter dwelling on Burwash Bay, one of a number of such structures that have been found on Nettilling and Amadjuak lakes.

Evidence of occupation during the early part of this century has been found at several sites. This typically includes considerable surface debris, rifle and shotgun cartridges (but also bow and arrow parts!), saws and files, as well as the use of metal and wood instead of stone and bone in otherwise familiar Thule-style implements (Figure 10). Although use of the interior region has declined recently, Inuit elders from Iqaluit, Pangnirtung and Cape Dorset vividly recall their experiences in travelling overland in summer to the interior.

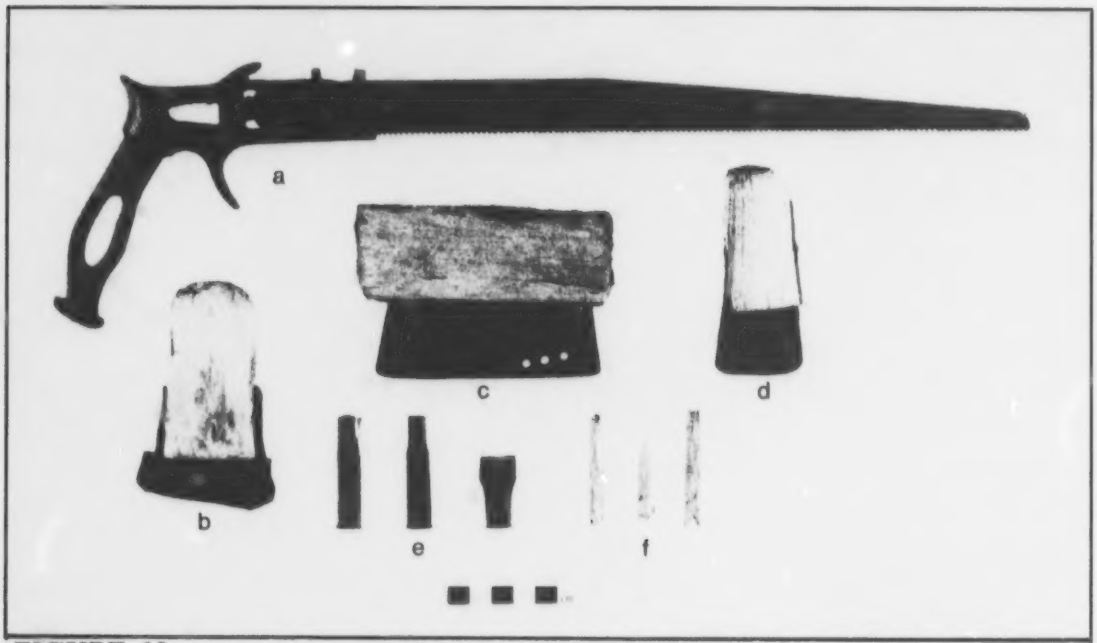


FIGURE 10: Evidence of occupation early in this century has been found at several sites. In addition to obviously modern implements such as the saw (a) and cartridge cases (e), there are two wood and steel scrapers (b,d) that were traditionally fashioned from caribou scapulae and a cutting and scraping tool (c) with a steel blade replacing what would have been slate in the past, as well as arrow parts (f).

Although many of the archaeological field data are still under analysis, clearly settlement in the large lakes region was a periodic option through the last four millennia. Our ethnographic evidence suggests that movement to the interior is triggered by changes in the number and distribution of caribou. Studies in Alaska and Greenland (Burch 1972; Meldgaard 1986) have demonstrated the cyclic nature of caribou population dynamics, and have related these fluctuations to increased predation and overgrazing. However, effects of climatic fluctuations on primary production and especially on winter range conditions are seen as the primary influence. There is evidence of similar fluctuations in caribou numbers and distribution in Baffin Island; therefore, our archaeological study is organized within an ecological-interpretive framework, modelling human behaviourial adjustments as responses to changing herd conditions.

CORRELATION

It would be premature to propose a detailed chronology of the large lakes region at this early stage in our investigations. Archaeological surveys are far from complete, and many promising sites have yet to be tested or excavated. Likewise, the paleoenvironmental record is still under study, as we analyze and calibrate the pollen record against a regional climatology that is itself being studied. However, we can offer a tentative interpretation of the available archaeological evidence against a paleoenvironmental sequence inferred mainly from the Frobisher Bay pollen record (Figure 11).

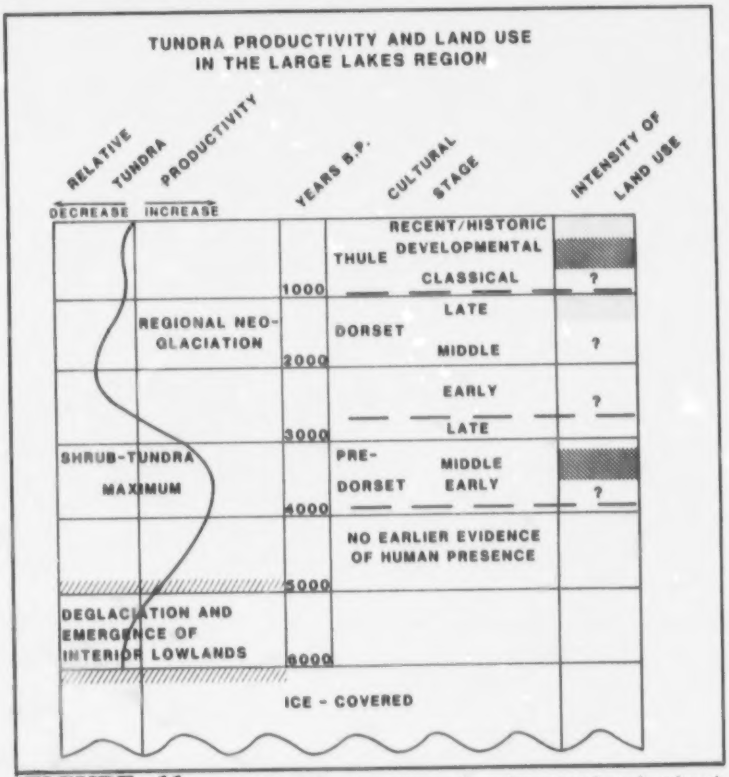

TUNDRA PRODUCTIVITY AND LAND USE
IN THE LARGE LAKES REGION
RELATIVE TUNDRA PRODUCTIVITY
DECREASE
INCREASE
YEARS B.P.
CULTURAL STAGE
INTENSITY OF LAND USE
RECENT/HISTORIC
THULE
DEVELOPMENTAL
CLASSICAL
1000
?
REGIONAL NEO-GLACIATION
DORSET
LATE
MIDDLE
2000
?
EARLY
?
LATE
3000
SHRUB-TUNDRA MAXIMUM
PRE-DORSET
MIDDLE
EARLY
4000
?
NO EARLIER EVIDENCE OF HUMAN PRESENCE
5000
DEGLACIATION AND EMERGENCE OF INTERIOR LOWLANDS
6000
ICE - COVERED

FIGURE 11: A tentative chronology of environmental and cultural developments in the large lakes region. Some gaps in the cultural record (?) may be filled as a result of further surveys and excavations.

Deglaciation and emergence came late to the interior lowlands, but plant colonization and succession were rapid. The first people to arrive, the Pre-Dorset, found a highly-productive land in a milder-than-present climate, under which conditions they flourished for perhaps a millennium or more. With regional cooling around 3,000 yr B.P., winter occupation of the interior became untenable. Perhaps there was a long hiatus until Dorset people, better-adapted to colder climate, found their way into the interior on a seasonal basis. Their successors, people of the Thule Culture, showed little hesitation in exploiting the interior seasonally and, when short-term conditions were favourable, year-round.

So much for the outline. There is an intriguing inland arctic ecosystem that humans evidently occupied over much of the last four millennia. The nature of that system and how it has changed over time remain to be more fully determined.

ACKNOWLEDGEMENTS

This work has benefited greatly from information provided by the people of Iqualuit, Kingnait, and Pangnirtung, and from discussions with Michael Ferguson, Baffin Regional Wildlife Biologist. Assistance in the field has been given by students from our and other institutions and from the northern communities. Financial and material support has been provided by the Natural Sciences and Engineering Research Council, the Social Sciences and Humanities Research Council, Indian and Northern Affairs Canada (through both the Northern Scientific Training Grants and the use of the Iqualuit Laboratory), the Atmospheric Environment Service, the Government of the Northwest Territories, the Boreal Institute for Northern Studies, the Faculty Development Program of the University of Wisconsin at Oshkosh, and the University of Windsor Research Board.

REFERENCES

Blake, W., Jr. 1966. End moraines and deglaciation chronology in northern Canada with special reference to southern Baffin Island. Geological Survey of Canada, Paper 66-26:1-31.

Boas, F. 1888. The Central Eskimo. Sixth Annual Report of the Bureau of American Ethnology. Smithsonian Institution. pp. 400-675.

Burch, E.S., Jr. 1972. The caribou/wild reindeer as a human resource. American Antiquity 37:339-368.

Davis, P.T. 1980. Late Holocene glacial, vegetational, and climatic history of Pangnirtung and Kingnait Fiord area, Baffin Island, N.W.T., Canada. Ph.D dissertation, University of Colorado, Boulder.

Jacobs, J.D. and L. Grondin. 1988. The influence of an arctic large lakes system on mesoclimate in south-central Baffin Island, N.W.T., Canada. Arctic and Alpine Research 20:212-219.

Jacobs, J.D., W.N. Mode, C.A. Squires, and G.H. Miller. 1985A. Holocene environmental change in the Frobisher Bay area, Baffin Island, N.W.T. Géographie physique et Quaternaire 39:151-162.

Jacobs, J.D., W.N. Mode, and E. Dowdeswell. 1985B. Contemporary pollen deposition and the distribution of *Betaula glandulosa* at the limit of Low Arctic tundra in southern Baffin Island, N.W.T., Canada. Arctic and Alpine Research 17:279-287.

Jacobs, J.D. and D.R. Stenton. 1985. Environment, resources, and prehistoric settlement in upper Frobisher Bay, Baffin Island. Arctic Anthropology 22:59-76.

Maxwell, J.B. 1980. Climate of the Canadian Arctic Islands and adjacent waters, Volume 1. Atmospheric Environment Service, Downsview, Ontario.

Maxwell, M.S. 1985. Prehistory of the eastern Arctic. Academic Press, Orlando, Florida.

McGhee, R.J. 1969/1970. Speculation on climatic change and Thule culture development. Folk 11/12:173-184.

McLauchlan, D.P. 1944. Report of patrol from Lake Harbour to Cape Dorset, Nettilling Lake, Pangnirtung, and Frobisher Bay by dog team, March 27th - May 25th, 1944. National Archives of Canada files, "G" Division, Royal Canadian Mounted Police.

Meldgaard, M. 1986. The Greenland caribou - zoogeography, taxonomy, and population dynamics. Meddelelser om Grønland, Bioscience 20:1-88.

Millward, A.E. (Editor). 1930. Southern Baffin Island: an account of exploration, investigation and settlement during the past fifty years. Department of The Interior, Ottawa.

Minc, L. 1986. Scarcity and survival: the role of oral tradition in mediating subsistence crises. Journal of Anthropological Archaeology 5:39-113.

Mode, W.N. and J.D. Jacobs. 1985. Holocene vegetation and climate, southern Baffin Island, N.W.T., Canada. Geological Society of America, Abstracts with Programs 17:319.

Neatby, L. H. 1977. My life among the Eskimos: the Baffinland journals of Bernard Adolph Hantzsch 1909-1911. Mawdsley Memoir Series 3. Institute for Northern Studies, University of Saskatchewan, Saskatoon.

Porsild, A.E. 1958. Geographical distribution of some elements in the flora of Canada. Geographical Bulletin 11:57-77.

Short, S.K., W.N. Mode, and P.T. Davis. 1985. The Holocene record from Baffin Island: modern and fossil pollen studies. In: Quaternary Environments: Eastern Canadian Arctic, Baffin Bay and Western Greenland. Edited by: J.T. Andrews. Allen and Unwin, Ltd. Boston.

Soper, J.D. 1928. A faunal investigation of southern Baffin Island. National Museum of Canada, Bulletin 53.

______. 1981. Canadian Arctic recollections: Baffin Island 1923-1931. Mawdsley Memoir 4. Institute for Northern Studies, University of Saskatchewan, Saskatoon.

Stenton, D.R. 1983. An analysis of faunal remains from the Peale Point Site (KkDo-1), Baffin Island, N.W.T. M.A. thesis, Department of Anthropology, Trent University, Peterborough, Ontario.

______. 1986. Mitigation of the Sandy Point Site (L1Dv-10), Baffin Island, N.W.T. Report on file, Prince of Wales Northern Heritage Centre, Yellowknife, N.W.T.

______. 1987. The Nettilling Lake Archaeological Project, Baffin Island, N.W.T. Report to the Archaeological Survey of Canada. Department of Anthropology, University of Alberta, Edmonton, Alberta.

[illegible]
July 17 87
Iqaluit

Illustrated by Brenda Carter

HISTORY AND RECENT EXPEDITIONS

DISCOVERIES AND EXPLORATIONS OF THE CIRCUMPOLAR LANDS AND SEAS FROM ANTIQUITY TO THE TWENTIETH CENTURY

J.R. Weber[1] and E.F. Roots[2]

Abstract: This paper sumarizes information on expeditions that led to the discovery and exploration of the Arctic Ocean and its margin since the voyage of Pytheas about 320 BC. The exploration of the Canadian Arctic Islands is viewed in this perspective. It took more than three centuries to map all of those islands beginning with Frobisher's exploration of southwestern Baffin Island in the sixteenth century and virtually ending with Stefansson's discovery of several islands in the northwestern extremity of the archipelago during the Canadian Arctic Expedition of 1913-1918. However, Prince Charles, Air Force and Foley islands remained undiscovered until 1948, when a Royal Canadian Air Force Lancaster spotted them.

Résumé: Cet article résume l'information sur les expéditions qui ont permis la découverte et l'exploration de l'océan Arctique et de ses marges, depuis le voyage de Pythéas vers l'an 320 A.C. C'est dans cette perspective qu'est examinée l'exploration des îles de l'Arctique canadien. Il a fallu plus de trois siècles pour cartographier l'ensemble de ces îles, depuis l'exploration par Frobisher du sud-ouest de l'île Baffin, au 16e siècle, jusqu'à la découverte par Stefansson de plusieurs îles dans l'extrémité nord-ouest de l'archipel pendant l'expédition de 1913 à 1918 dans l'Arctique canadien. Cependant, les îles Prince-Charles, de l'Aviation et Foley ne furent découvertes qu'en 1948, lorsqu'un avion "Lancaster" de l'Aviation royale du Canada les a repérées.

INTRODUCTION

The history of geographical exploration of the arctic regions has been told many times, and there is an enormous literature dealing with expeditions and geographical discoveries. This is a summary of those expeditions, starting with the earliest recorded voyages, that led to the discovery of the Arctic Ocean and its scientific exploration during the last two centuries. Among the circumpolar lands, the Canadian Arctic Islands and northern Greenland, because of their intricate geography and ice conditions that are so much more severe than elsewhere, were the most difficult to explore. It took more than three centuries to map all of the Arctic Islands starting with Martin Frobisher's exploration of Hudson Strait and southwestern Baffin Island in the sixteenth century, and ending with Vilhjalmur Stefansson's discovery and mapping of the last of the Queen Elizabeth Islands during the First World War. For a more complete history of the geographical discovery and scientific exploration of the Arctic Ocean region, see Weber and Roots (1989).

The reader is referred to the maps on the inside covers of this book for geographical place-names used in this section.

---

[1] Geophysics Division, Geological Survey of Canada, 1 Observatory Crescent, Ottawa K1A 0Y3
[2] Science Advisor, Environment Canada, Ottawa, Ontario K1A 0H3
Geological Survey of Canada Contribution No. 50588

FROM ANTIQUITY TO MERCATOR AND BARENTS

The first polar explorer on record was Pytheas from the Greek colony of Massilia, the modern Marseilles. About 320 BC, he sailed in search of the tin which had mysteriously appeared from time to time in the markets of Massilia, coming, so rumour said, south through Gaul from some remote and unknown northern land. Navigating by sun and stars he steered his square-sailed Greek galley to Brittany and to Cornwall, the source of the tin. After sailing northward from the British Isles for six days, he reached another land, which he identified as Thule, where the nearby sea was frozen. Whether this was Iceland or northern Norway has been much debated; but the consistency with which the wealth of information brought back by Pytheas was reported and used by many contemporaneous sources leaves no doubt that he reached arctic latitudes and spent some time there. Observations on the relative positions of the stars, the midnight sun, the differing lengths of days and nights as the seasons progressed, the connection between the tides and the phases of the moon, large sea mammals, the unexpected phenomenon of the freezing of the sea was mystifying and terrible to warm-ocean sailors. These observations were completely new to Mediterranean geographers and scholars, so that the words to describe some of them had to be borrowed from Pytheas' Celtic and Norse contacts. So convincing was his information that this one extended voyage significantly enlarged the known world and brought arctic phenomena into what was then the mainstream of European scientific knowledge and literature (Chevallier 1984).

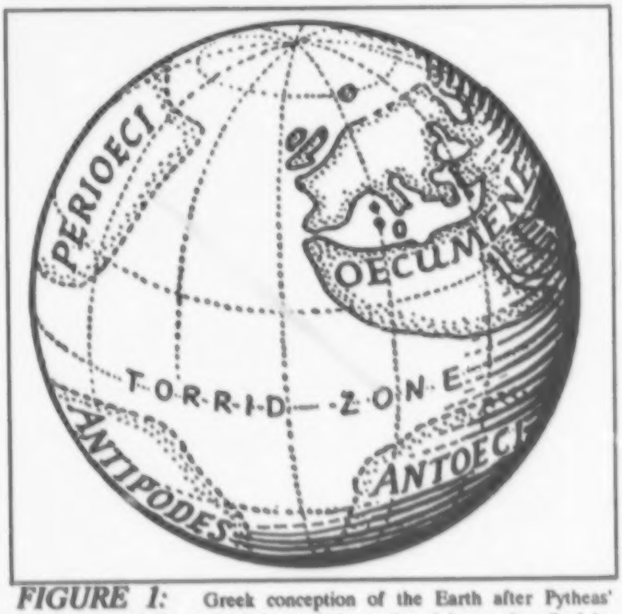


FIGURE 1: Greek conception of the Earth after Pytheas' discoveries and Eratosthenes' calculations: the globe as described by Crates (about 150 BC). It satisfied symmetry by inventing, in addition to the known inhabited world (the Oecumene), three other populated continents: Perioeci (peoples around the globe from the Oecumene), Antoeci (peoples below the Oecumene), and the Antipodes (peoples on the opposite of the globe) (Raisz 1948).

Pytheas' observations paved the way for Eratosthenes (220 BC) to portray the Earth as a sphere of finite size and to devise ways to calculate its circumference and axial tilt (Figure 1). Later geographers and cartographers such as

Strabo and Ptolemy incorporated this information, embellished with fanciful details and reports from various other sources, to develop a European concept of the arctic regions that remained essentially unchallenged for the next thousand years.

Apparently Iceland was already settled by Irish monks, when the Norsemen arrived about 870 AD. The settlement of Greenland by Eric the Red around 985 AD was soon followed by the discovery of Baffin Island, Labrador, Newfoundland and possibly Nova Scotia by Norsemen. Norse travellers from West Greenland reached St. Helena Island at the west end of Jones Sound in the central Canadian Archipelago and Bache Peninsula on Ellesmere Island.

The earliest account of a penetration into the Arctic Ocean Basin is in the writings of King Alfred the Great of England, who about 890 AD was informed by a Norwegian chieftan named Othere (Ottar), from Halagoland in southern Norway, that some decades earlier he had followed the Scandinavian coast to the north and east - "he was anxious to know how far the land extended, and whether any people lived beyond the wasteland" (Bosworth 1855; Sweet 1883, p. 30). Othere sailed around the North Cape and the Kola Peninsula into the White Sea, where he encountered the Finns from whom he thereafter annually collected produce and tribute. This voyage was followed by considerable coastal trade, and the extension of Norwegian sovereignty from the White Sea to Iceland. Norway's rule became absolute. A royal proclamation in 1294 forbade foreigners to sail north of Bergen and forced English and Dutch merchants to buy produce from all northern waters and lands in the harbour of that town. Even Norwegian ships were subjected to royal restrictions in venturing northward. This principle of mare clausum appears to have effectively prevented further exploration of the Arctic Ocean until well into the sixteenth century (Blom 1984).

Speculation on the geography of northern regions continued, however, and there were several attempts to compile known and imagined records. Early in the fifteenth century, a Dane, Claudius Clavus, made two maps of the North extending Ptolemy's atlas which showed only Terra Incognita and Mare Congelatum north of 63° latitude (which perhaps was Pytheas' northern limit). Presumably using information gathered from traditional Norse mariner's sailing stories, Clavus placed Iceland midway between Norway and Greenland. Norse knowledge of impenetrable sea ice across the northern North Atlantic may also have been the basis for the interpretation that a continuous land bridge between Greenland and

Europe closed off Mare Congelatum. A map showing both sides of the Atlantic in reasonable scale and proportions based on Norse and English voyages to North America was drawn in Iceland by Sigurdur Stephansson in 1570 (Figure 2), but it retained the land bridge. Other maps of the time, for example that of Ortelius published the same year, do not show land connecting Europe and Greenland. Greenland is depicted as a modest island of realistic shape, and a long marine passage leads around the north of North America to the "Strait of Anian" and the Pacific Ocean.

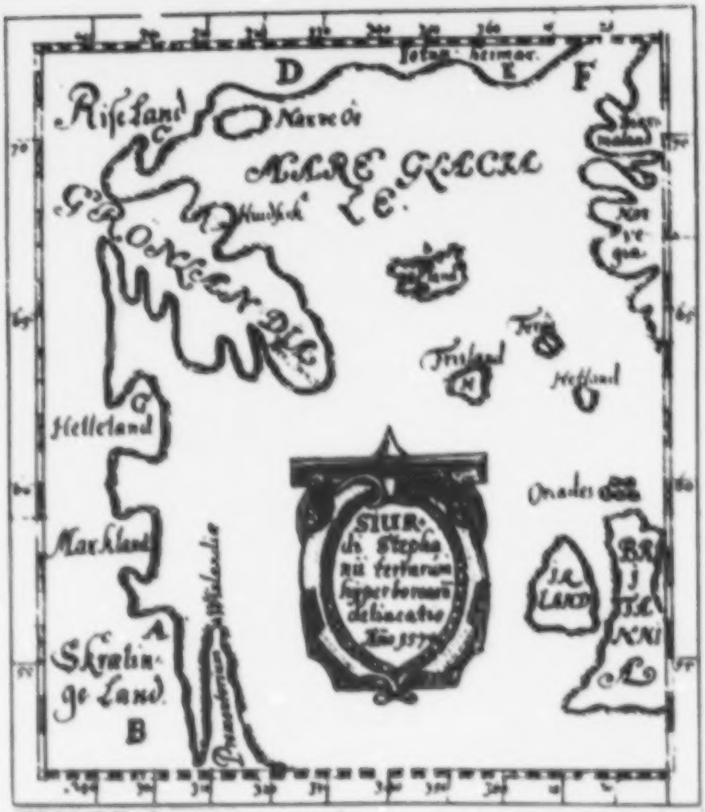


FIGURE 2: Map of the North Atlantic region drawn in Iceland by Sigurdur Stephansson in 1570. Note the rectangular coordinate system used for latitude and longitude. Stephansson appended explanatory notes to this map in which he remarks that the Atlantic Ocean was closed by Jotunheiman (the home of giants). Royal Library, Copenhagen.

In 1588, Nicolo Zeno published a story, now considered fiction, of the voyages of two of his ancestors to the Arctic in 1380. He illustrated the story with an imaginative "chart" based partly on the maps of Clavus and later cartographers. The popularity of this drawing was such that "Zenian geography" was accepted as an improvement on previous maps. Genuine contemporary discoveries, such as those of Frobisher, were force-fitted into Zeno's map and, thereby, falsified (Wallis 1984).

From the time of the early Greek and Roman globes that showed an all-encompassing ocean beyond the known and unknown lands (Figure 1), little attention had been given to what lay beyond the travelled world, including the polar region (Rey *et al.* 1984). Scandinavian legends, however, in which a polar maelstrom swirled about a central rock, surrounded by four islands, peopled by pygmies, and between which strong currents of water rushed to the Pole, had become known in southern Europe through a widely quoted book, "De Inventione Fortunata qui liber incipit a gradua 54 usque ad polum" ("... which book begins in the description at latitude 54 degrees and goes as far as the pole") attributed to Nicholas of Lynne and published in Italy in 1360. The book is of interest today because it shows that, in the fourteenth century, degrees of latitude were already in widespread use for geographical description and that the North Pole was a widely understood concept. The mythical geography of the north polar regions, however, described in this book became the chief source of ideas for cartographers wishing to fill in blanks on the arctic map.

One of the earliest attempts to draw a map of the polar basin was by Johannes Ruysch of the Netherlands, whose 1507 map is included as Plate 1 in the 1508 edition of "Ptolemy's Geography" published in Rome. Ruysch quotes his authority for the central part of his map by a legend on the map:

> "In the book 'De Inventione Fortunata' it may be read that there is a high mountain of magnetic stone, 33 German miles in circumference. This is surrounded by flowing 'mare sugenum' which pours out water like a vessel through openings below. Around it are four islands of which two are inhabited. Extensive desolate mountains surround these islands for 24 days' journey, where there is no human habitation" (translation in Nansen 1911, Volume 2, p. 289).

The most influential of the map-makers to take their ideas from "De Inventione Fortunata" and similar stories was the Flemish cosmographer and cartographer Gerhard Kremer (Mercator), who in 1569 produced a world chart with a polar projection insert of the Arctic Ocean. This map differs in important ways from his earlier 1538 map. Although his 1569 map shows known land and seas as accurately as knowledge then permitted, the central Arctic Ocean is a fanciful cartoon based on "Inventione Fortunata" and the Scandinavian legends. The result was to mislead generations of later explorers. Over the next 30 years, Mercator improved his map and added details from successive discoveries of the known coasts and lands, but never abandoned the imaginary central ocean land masses (Figure 3). Other well-known world maps of the period, notably that of Ortelius, 1570, also fill the Arctic Ocean with four mythical islands. More cautious map-makers, notably the Dutch navigator Willem Barents, produced circumpolar maps depicting only the known and verified lands, at least within the sector of the then discovered lands, between Davis Strait and Novaya Zemlya (Figure 4). However, these more accurate renditions had less influence on geographers' concepts of the Arctic Ocean Basin.

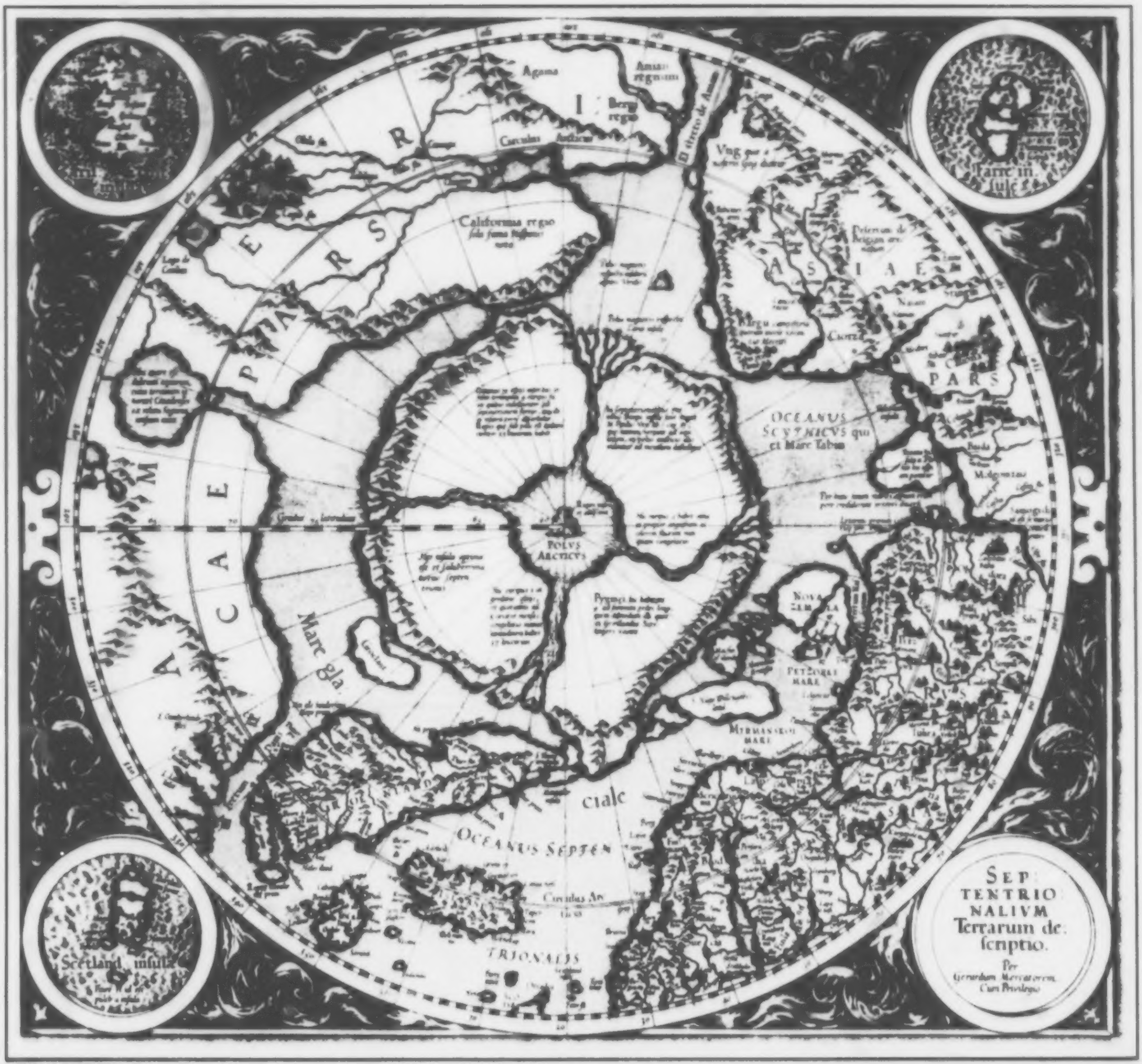

Agama
Anian regnum
Bergi regio
Circulus Arcticus
Californias regio
AMERICAE PARS
ASIAE PARS
OCEANUS SCYTHICUS qui et Mare Tabin
POLUS ARCTICUS
NOVA ZEMLA
PETZORKE MARE
MURMANSKOI MARE
Mare glaciale
OCEANUS SEPTENTRIONALIS
Scetland insulae
Farre insulae
SEPTENTRIONALIUM Terrarum descriptio.
Per Gerardum Mercatorem. Cum Privilegio

FIGURE 3: **Gerhard Mercator's revised circumpolar map of the Arctic Ocean, Septentrionalium terrarum descriptio (1595).** National Archives of Canada, NMC-29431.

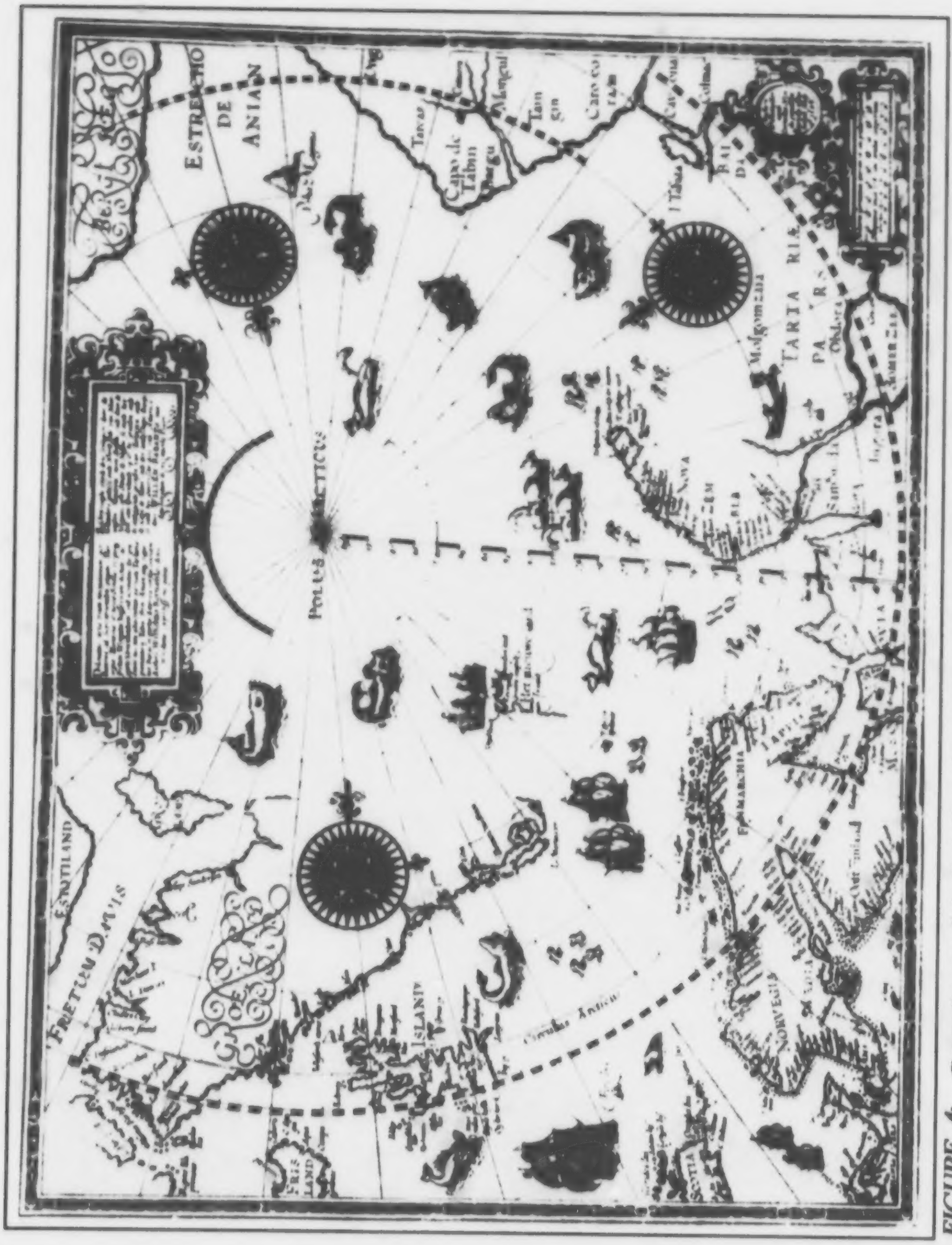

ESTRECHO DE ANIAN
POLUS ARCTICUS
FRETUM DAVIS
ESTOTILAND
TARTARIA
NORVEGIA
ISLANDT
FRISLAND
SCOTIA
Circulus Arcticus

FIGURE 4: Circumpolar map of the Arctic Ocean drawn by Willem Barents (1598). National Archives of Canada, NMC-10299.

An interesting detail of Mercator's arctic maps, and of many other European maps of the period, is the inclusion of the "Strait of Anian" that connects the Arctic Ocean with the Kingdom of Japan. The concept of a strait separating Asia from North America was first embodied on maps about 1540, prior to any recorded discoveries in the region (Falk 1984). Many maps produced during the next 60 years show this strait, and on several of these the geographical position and outlines bear quite close resemblance to Bering Strait. Many modern scholars feel that the representations are pure speculation and the resemblance to actual geography is coincidental (Fisher 1984).

The fanciful ideas from the Scandinavian legends and "De Inventione Fortunata" have been very durable. The concept of a magnetic mountain as an attractor for the compass persisted long after William Gilbert showed that the Earth as a whole generated the magnetic forces. The notion of an open north polar sea was a driving force for centuries of later exploration. The concept of an aperture at the pole that led to the interior of the Earth developed later into "Symmes Hole", and still further into the idea of a hollow earth, popular with science fiction writers from Jules Verne ("Adventures of Captain Hatteras", 1864; see Barr, this volume) to Richard Lupoff ("Circumpolar!", 1984). A number of apparently serious quasi-philosophical tracts that ignore scientific evidence still find a ready popular sale among those wishing to believe in, or be titillated by, a "hole at the Pole" (Bernard 1976).

SEARCH FOR THE NORTHERN SEA ROUTE TO THE KINGDOMS OF CATHAY

In the sixteenth century, a fresh impetus was given to arctic exploration by the search for a northern route to the Indies, China and Japan, or the kingdoms of Cathay as they were called. This search was, in part, the result of the Treaty of Tordesillas in 1494, which divided the right of exploration and acquisition of the then known world into two domains, the western being granted to Spain, the eastern to Portugal. Although the treaty extended from Pole to Pole, the Papal bull giving international sanction to the treaty excluded lands already in possession of a Christian power and did not prevent northern nations from exploring the coasts of lands that they claimed (Theutenberg 1984). Discovery of a northern route to the Orient would, thus, circumvent the Spanish and Portugese blockades. Until the eighteenth century, the main motive of arctic voyages remained the search for a northern passage to the Pacific and the oriental kingdoms of Cathay. The concept of a navigable northern trade route to the Orient was first strongly promoted in 1527 by the English merchant adventurer Robert Thorne. In addition to political motives, it was bolstered by two misconceptions that, despite growing evidence, were to persist for centuries: (1) that sea ice formed only near coasts and that continuous arctic summer sun would maintain an open ice-free polar sea; and (2) a mistaken notion of the distance to China based, apparently, on Marco Polo's erroneous description of the width of Asia (Saladin d'Anglure 1980). This led to an assumption that a route through the North-West Passage would be much shorter than one to the east.

During the reign of Elizabeth I, in the second half of the sixteenth century, the British ventured both to the northeast and to the northwest. Richard Chancellor sailed as far as the southern tip of Novaya Zemlya, where he was forced back by an ice barrier at the entrance to the Kara Sea. In three voyages, 1576-1578, Martin Frobisher, probing Hudson Strait and the bays of southeastern Baffin Island, made the first contribution to arctic economic geology by bringing back pyritiferous mica schist that was mistaken for gold ore. This discovery precipitated two further expeditions in a frantic attempt to find gold - the first arctic gold rush.

In three carefully documented voyages, 1585 to 1587, John Davis explored the coasts of Greenland along Davis Strait. In 1594, four Dutch ships under the command of Willem Barents managed to penetrate the Kara Sea. Two years later, another Dutch expedition, commanded by Jon Rijp and Jacob Heemskerck with Barents as pilot, sailed beyond 80°N. On their way south, they discovered Spitsbergen with its waters abounding with seals, walruses and whales. Exploring further to the east, Heemskerck and Barents sailed around the northern tip of Novaya Zemlya, thus completing the outline of the major land areas north of Eurasia.

In 1609, the Netherlands forced Portugal to grant her full rights to the trade in eastern waters. Thus, the Dutch had no further need for the arctic sea route, and abandoned its search for a northern route to the Indies. The British, however, were still opposed by Spain and continued the quest, and in 1616 Robert Bylot, with William Baffin as navigator, nearly solved the problem of the North-West Passage. Bylot was by this time on his fifth arctic exploratory voyage, Baffin on his sixth. They navigated the 50-ton ship *Discovery* along

Greenland's west coast to Melville Bay, rounded the head of what is now Baffin Bay, crossed Smith Sound at the south end of Nares Strait and explored the eastern ends of Jones and Lancaster sounds. Naming all the major land and water features, they recorded most of the outline of western Greenland and the eastern Canadian Arctic Islands. Baffin's detailed maps and journals from this voyage, however, were not preserved. The only record of his survey that can be identified today is in the circumpolar chart "Polar Map or Card" produced in 1635 by Luke Foxe, an acquaintance of Baffin, to illustrate his own 1631-1632 explorations in Hudson Bay. The map shows in excellent detail the then-known arctic coastlines of North America, Spitsbergen and Scandinavia (Taylor 1955; Wallis 1984). Otherwise, and in part possibly due to commercial rivalry, Baffin's findings were forgotten or doubted. They were not rediscovered until the nineteenth century.

The seventeenth century arctic maritime discoveries, launched by merchant guilds and city companies seeking a trade route to the Orient, were supplemented by the unrecorded voyages of whalers and sealers who followed into subarctic and arctic waters. The Dutch discovery of rich marine resources in the Barents Sea and around Spitsbergen soon led to a fierce rivalry between English and Dutch whalers and sealers. The extension of whaling grounds into Melville Bay, western Baffin Bay and Hudson Strait was mainly an English operation, although Dutch, Danish, French and Portugese ships are known to have been active. On land the men of the Hudson's Bay Company (founded in 1670), and other trappers, hunters and voyageurs, had already started to push the North American frontier towards the Arctic Ocean. Similarly, the Russian economic empire was expanding eastwards across Siberia and along the Asian arctic coast.

EIGHTEENTH CENTURY STRATEGIC EXPLORATIONS

With the onset of the eighteenth century, motives and methods of polar exploration changed. Exploration became largely an instrument of government policy, and the national navies of Britain, France and Russia replaced the private groups and merchant adventurers of former years. In Britain, the dominant role of the Royal Navy in the organization and conduct of polar exploration became a tradition that has continued almost to the present day. Most important, however, the eighteenth century saw the beginning of scientific exploration. The new national academies of science that sprang up in England, France and Russia played a very important part as advisors of governments in all scientific matters, and as initiators of exploration.

The eighteenth century was one of Russian achievement in the Arctic. All activities, however, were land-based or coastal. The question of whether Asia and America are joined had been solved by a Siberian Cossack, Simon Dezhnev. In 1648, he sailed from the Kolyma River on the eastern Siberian arctic coast around East Cape (Mys Dezhneva) through Bering Strait to the mouth of Anadyr River. Dezhneva's discovery was reported to the authorities in Yakutsk but remained officially unknown in Europe until well into the first half of the eighteenth century, although rumours of the voyage may have reached the Imperial Court in St. Petersburg earlier. Such rumours may have stimulated Tsar Peter the Great to launch a series of grandiose projects of exploration. The first of these under the leadership of Vitus Bering, was a huge expedition that included 200 horses, which left St. Petersburg in 1725 and crossed Siberia overland. After immense hardships, it reached the coastal town of Okhotsk. In 1729, Bering was able to circumnavigate Kamchatka Peninsula and sail up Bering Strait as far as Mys Dezhneva, but due to the lateness of the season and dense fog, he had to return without having sighted the Alaskan coast. In 1732, on a separate expedition, Ivan Fedorov and Mikhail Gvozdev charted Cape Prince of Wales, and King Island and the Diomede Islands in Bering Strait, thus completing the exploration of Bering Strait. It was not until 1740, on a subsequent expedition, that Bering made landfall in Alaska. These expeditions were supplemented by many surveys by the Imperial Admiralty College, and by 1746 the whole of the Siberian arctic coast from the River Ob to Mys Dezhneva, Bering Strait and the Anadyr and Kamchatka peninsulas had been explored and charted.

In eastern Siberia and Bering Strait, exploration was followed by trade, and by the formation of trading companies. Catherine the Great encouraged a new brand of Russian imperialism across Bering Strait and southward along the North American coast during the second half of the eighteenth century. By the first quarter of the nineteenth century, Russia - in the form of the government sponsored Russian-American Company - was firmly established in Alaska. A rigorous ukase, or ban, proclaimed by Tsar Alexander I in 1818, effectively closed the North Pacific to non-Russians (Roots 1986), and the problem of finding a North-West Passage around the northern extremity of Canada became a strategic priority for Great Britain. The search for this passage was to preoccupy the British Navy for more than half a century following the Napoleonic Wars.

Among the remarkable advances in science of the eighteenth century, the study of magnetism was one of the most important. The formulation of general laws, or principles, of planetary magnetism and the construction of magnetic charts led to a need for widespread, simultaneous observations of magnetic variation and dip. Consequently, the recording of magnetic observations became a prime duty of naval expeditions. The re-emergence of scientific astronomy, and the study of the relation of the Earth to the motions of other planets and "heavenly bodies" became another powerful scientific incentive for global exploration and voyages to distant locations to observe eclipses and make celestial observations.

Advances in technology, such as the invention of John Hadley's reflecting quadrant in 1731, the introduction of John Harrison's chronometer in 1762, the publication by Nevil Maskeleyne in 1767 of the first nautical almanac, the availability of better ships, including rot-resistant rope for rigging, and the techniques of preventing scurvy during long voyages, boosted exploration.

Between 1770 and 1772, Samuel Hearne of the Hudson's Bay Company, accompanied by Indian guides, made an overland trip from Churchill to the Coppermine River in search of the source of native copper, and also to determine whether a low-latitude North-West Passage could be found north of Churchill. In July 1771, Hearne reached the mouth of the Coppermine River, the first white man to stand on the north coast of the American continent. His explorations showed conclusively that there was no easily navigable passage between eastern North America and the Pacific Ocean (Keating 1970). Hearne brought back a sample of copper but the company made no attempt to exploit the copper deposits.

In 1773, Captain Constantin John Phipps led a scientific expedition into the Arctic Ocean. The plan was for a "voyage made towards the North-Pole to be of service to the promotion of natural knowledge" (Royal Society 1782, p. 158). The voyage was sponsored by the Royal Society of London and approved by the Admiralty and King George III. Prevented by heavy ice from reaching more than a short distance north of Spitsbergen, his two ships, the sloops *Racehorse* and *Carcass*, explored the ice edge from near Greenland to White Island. Among the better known results of Phipps' expedition were: the first scientific description of the polar bear (*Ursus maritimus* Phipps); measurement of the gravity difference between northernmost Spitsbergen and Greenwich; the first measurements of the West Spitsbergen and East Greenland currents; and the first temperature and salinity profiles and depth-soundings of Arctic Ocean waters. Although there were no new geographical discoveries, the expedition is mentioned because it was an important event in the story of Arctic science. It represented the first multidisciplinary field research expedition into the Arctic Ocean region and set the pattern for nineteenth century polar expeditions.

Except for Phipps' expedition, no British ships ventured into the High Arctic during the eighteenth century. A number of voyages were undertaken into Hudson Bay in search of the North-West Passage, motivated primarily by a desire to outflank the French fur trade in the south. During that time, British exploratory interests were mainly preoccupied with the great Pacific and Antarctic voyages of James Cook and with operations to oust the French and secure dominion over Canada.

BRITISH ROYAL NAVY EXPLORATIONS OF THE NINETEENTH CENTURY

Following the battle of Waterloo, military or territorial goals became closely connected to trade, and except for the North Pacific the seas were for the first time free to all ships. Exploration expanded dramatically. Interest in scientific knowledge among the emerging middle classes (a development influenced by the industrial revolution) found an expression in private societies in which scientific discoveries were followed by a popular, as well as professional, membership. Geographical societies, in particular, became centres of influential and informed public opinion and took a leading role in promoting polar exploration. The first was the Société de Géographie in Paris, founded in 1821, followed by the Gesellschaft für Erdkunde in Berlin (1828) and the Geographical Society of London (1830). Polar exploration during the first half of the nineteenth century was predominantly a naval affair, and naval officers with experience of polar voyages were among the most active members of the new geographical societies. The membership also included many owners of whaling and sealing ships. Through these members a wealth of practical knowledge accumulated and the geographical societies became centres of advice on the organization and techniques of polar exploration.

The British Navy was foremost in the revival of polar exploration. The motive was no longer simply a search for a passage to Cathay but included the delineation of the Arctic coast of British North America and the discovery of new lands of exploitable resources. Britain was keenly aware of its potential rivals, the youthful and ebullient United States to the south, and the Russian Empire to the west. The latter was in control of Alaska and the coasts of the North Pacific from Vancouver Island to Vladivostok and had extended trading posts as far south as San Francisco. By taking the initiative in northern exploration, the British Admiralty hoped to forestall rival operations in the Arctic.

It is indicative of the politics and mood of the times that British naval interest in Arctic Ocean exploration was sparked by commercial whaling interests and made possible by a surplus of new, well-built, capable vessels and trained officers left from the close of the Napoleonic wars in 1815. The Second Secretary of the Admiralty, Sir John Barrow, was dedicated to the discovery and traverse of the North-West Passage, and was a principal exponent of the widely held view that polynyas in the pack-ice of the North Atlantic were evidence of "a freedom of movement to the north, including open water in the neighbourhood of the Pole" (Kane 1856, Volume 1, p. 307). Barrow stated with conviction that "... if, therefore, the great polar basin should be free of land, the probability is that it will also be free of ice" (Barrow 1818, p. 374). The whaling captain and scientist William Scoresby, Jr., who had more than 20 years experience in the ice and who had made a careful survey of the coasts of Greenland and compiled the first technical description of polar ice, on the other hand considered the idea of an open polar sea to be "altogether chimerical". He proposed to "... reach the Pole by travelling across the ice from Spitzbergen" (Scoresby 1818, p. 328). Scoresby noted strong variations in the severity of ice between different decades, and urged taking advantage of the then comparatively ice-free situation to search for a North-West Passage. Together with his friend Sir Joseph Banks (president of the Royal Society and a colleague of Phipps), who had been a Lord of the Admiralty, Scoresby was able to revive scientific interest in polar exploration. However, his difference of opinion with Barrow appears to have prevented his taking further direct part (Taylor 1955, p. 22; Martin 1988; Levere 1988). As a result, in 1818, the British parliament passed an act to promote polar exploration. The government dispatched two major polar expeditions, one under Captain John Buchan, with Lieutenant John Franklin as second-in-command, to continue Phipps' work of 45 years earlier "to try to reach the Pacific by a northern route across the

Pole" (Smith 1877, p. 41), and the other, led by Commander John Ross, with Edward Parry as second-in-command, to check on Baffin's findings of 200 years before.

Buchan and Franklin, in *Dorothea* and *Trent*, barely got north of Spitsbergen before they were, like Phipps, stopped by impenetrable ice. Ross and Parry, however, in *Isabella* and *Alexander*, sailed up Davis Strait and rounded the head of Baffin Bay. Although they did not get as far north as their Elizabethan predecessors Bylot and Baffin, they confirmed Baffin's discoveries and applied his names to the main geographical features of the eastern Canadian Arctic Islands. Ross, however, failed to penetrate far into Lancaster Sound and inexplicably turned back, allegedly stopped by a chain of mountains he named Crokers Mountains.

The following year the Admiralty sent two ships, *Hecla* and *Griper*, under the command of Edward Parry to check on Ross' findings. Parry sailed through Lancaster Sound into Barrow Strait to discover Prince Regent Inlet, Wellington Channel and Cornwallis Island. He continued into Viscount Melville Sound, until stopped by ice at 110° longitude. The two ships wintered at Winter Harbour on Melville Island and the following summer, after penetrating a little farther west but finding ice still barring the way, they returned to England. Parry had with him, as he had also the year before, Captain Edward Sabine of the Royal Artillery, "... a gentleman well skilled in Astronomy, Natural History and various branches of knowledge" (Ross 1819, p. 10). Besides charting and sounding, Sabine measured water and air temperatures, studied the movement of tides and currents, made magnetic observations, and observed the effect of the Aurora Borealis on the electrometer and magnetic needle. While wintering on Melville Island, Sabine took pendulum measurements from which he subsequently determined the elipticity of the earth (Sabine 1821). Geological observations were made in Lancaster Sound and on a traverse to the interior of Melville Island.

Parry made two more attempts to navigate the North-West Passage. He sailed into Prince Regent Inlet and later entered Foxe Basin, on the southwest side of Baffin Island, where he discovered Fury and Hecla Strait, but ice conditions in each case prevented his sailing farther west.

The experiences of Phipps and Buchan did not dispel the idea of an open polar ocean. In 1827, encouraged by handsome rewards offered by the British Parliament for an attempt to reach the Pole, Parry and his crew sailed for Spitsbergen in the *Hecla*. From there, using two ships' boats fitted with iron runners and provisioned for 71 days, they sailed north until they reached solid pack ice. Hauling the boats on foot over the ice and launching them in intervening open water, they toiled for five weeks. They made very slow progress against the strong Transpolar Current, whose drift rate and direction they carefully recorded, and on July 26, 1827, having reached 82° 5' North latitude, they turned back.

John Ross made another, privately-funded attempt to find a passage to the west in 1828. He sailed in *Victory*, a paddle steamer that had been used in commercial service around the British coast. His second-in-command was his nephew, James Clark Ross, a specialist in the study of magnetism. Sailing south into Prince Regent Inlet, Ross mistook Bellot Strait, the key to the transit to Amundsen Gulf and the North-West Passage, for a bay (Savelle and Holland 1987), and continued to Boothia Peninsula where the *Victoria* was beset by ice. The ship remained icebound for three winters and was finally abandoned. During those years, James Clark Ross made long sled journeys with the Inuit. On one of these trips, to King William Island on 31 May 1831, he determined the location of the North Magnetic Pole.

While shipborne expeditions explored the northern waterways, overland parties, led mostly by naval officers, assisted by men of the Hudson's Bay Company, carried out many great journeys on the Arctic mainland. Chief Factor Peter Warren Dease, Dr. John Richardson and George Back travelled with Lieutenant John Franklin, and later led their own parties; and John Rae made extensive natural history observations as he filled in all but short stretches of the unknown coasts. Dease, Richardson, Back, Rae and Thomas Simpson were among these land explorers, who contributed most to the discovery and mapping of mainland Arctic Canada. By 1847, the arctic coasts of Alaska and Canada from Prudhoe Bay to Boothia Peninsula, including the southern shores of Victoria and King William islands, had been explored. During these explorations, the main areas of crystalline (Precambrian Shield) and sedimentary rocks along the North American Arctic coast became known.

The search for the North-West Passage along the southern route, via Coronation Gulf, had narrowed to the gap between Barrow Strait and Queen Maud Gulf. It was Sir John Barrow, promoter and organizer of the Ross and Parry expeditions, who persuaded the Admiralty to launch yet another expedition in search of the North-West Passage. Approval was motivated partly by the concern that ships of the growing American and Russian fleets might win the honour of the Passage; partly by the opportunity for testing, under adverse conditions, ships outfitted with the new screw propellers; and partly as a naval training exercise. In 1845, HMS *Erebus* and *Terror*, under the command of Sir John Franklin, left England for Lancaster Sound, where they were last sighted. From Barrow Strait, *Erebus* and *Terror*, after having circumnavigated Cornwallis Island, headed south along Peel Sound and eventually became beset in Victoria Strait. Weakened by scurvy and threatened by starvation, the men abandoned the ships in April 1848 and headed for the mainland in hope of reaching a Hudson's Bay post. None of the 134 men of the original ship's companies was ever seen again, although there is evidence that they may have encountered a small band of Inuit before they perished. As it turned out, Franklin had linked the eastern and western approaches to the North-West Passage.

By 1857, some 40 expeditions had been launched in search of Franklin and his men. The searchers converged by land and by sea from Bering Strait, Lancaster Sound and Hudson Bay, so that by 1860 almost all of the intricate geography of the Canadian Arctic Archipelago had been mapped. The commanders and ships best remembered from this period were Britishers: James Clark Ross (*Enterprise* and *Investigator*, 1847); Henry Kellett (*Herald* and *Plover*, 1847-1850; *Resolute* and *Intrepid*, 1852-1855; see Barr, this volume); Richard Collinson (*Enterprise*, 1850-1855); John Ross (*Felix*, 1850-1851); Horatio Austin (four ships, led by *Resolute*, 1850-1851); William Penny (*Lady Franklin* and *Sophia*, 1850-1851); Edward Belcher (five vessels, led by *Resolute* and *Assistance*, 1852-1854); Edward Inglefield (*Isabel*, 1852; *Phoenix*, 1854); Francis McClintock (*Fox*, 1857-1859); and Americans: Edwin deHaven (*Advance* and *Rescue*, 1850-1851); Elisha Kane (*Advance*, 1853-1855). Travelling overland from the south, John Richardson and John Rae (1847, 1848-1849, 1851, 1853-1854) discovered firm evidence indicating where Franklin had disappeared and added many details to geographic and scientific knowledge. In 1852, aboard *Isabel*, Commander Inglefield, on a private expedition sponsored by Lady Franklin, advanced into Nares Strait and showed that this channel led northwards into the Arctic Ocean, confirming earlier Norse maps and the sixteenth-century charts of Mercator and Ortelius.

LAST DISCOVERIES OF LANDS AND COASTS

By 1870, all the circumpolar mainland coasts, Novaya Zemlya, and most of the Canadian Arctic Islands had been explored. There still remained large unexplored and unmapped areas: the northern and northeastern coasts of Greenland and its vast interior, Ellesmere Island, the northwestern Queen Elizabeth Islands, much of Spitsbergen, Severnaya Zemlya and Franz Josef Land. Although the south coast of Ostrov Kotel'nyy had been visited in 1773 (Gorshkov 1980), the remaining New Siberian Islands had not been explored.

In 1871, the American explorer Hall sledged with Inuit to the northwesternmost limits of the Greenland Ice Cap, discovered Hall Land and saw Lincoln Sea. He also approached the Pole in his ship *Polaris* reaching latitude 82°11'N. In 1875, Captain George S. Nares sailed his ships, *Alert* and *Discovery*, north through Nares Strait to the edge of the Arctic Ocean. One object of the British expedition was to plant the Union Jack beyond America's farthest north. Equally important, however, were scientific objectives. Like their predecessor Parry 50 years earlier, parties of the expedition, led by Lieutenant Albert Markham, man-hauled boats over the pack ice and reached a point (83°20'N) a few miles beyond Hall's and Parry's highest latitudes. More significant to science, however, was their exploration and mapping of the northern coasts of Ellesmere Island and Greenland, where they carried out astronomical, geological, magnetic, tidal, meteorological, zoological, botanical and ethnological studies (Nares 1876, 1878). The site of their expedition base, Discovery Harbour (later named Fort Conger), was to become an important centre for scientific observation in the North American Arctic.

Baron A.E. Nordenskjöld was a Swedish chemist and mineralogist who became interested in Arctic science. He conducted a number of scientific expeditions to Spitsbergen and Greenland, later turning his attention to the problem of navigation of the North-East Passage. For Russia, Nordenskjöld argued, the navigation of the North-East Passage could be of vital importance; it might open up a commercial highway along the Siberian coast over which the mineral resources of the immense territories of eastern Russia could be brought cheaply to industrial Europe. In addition, there were strong scientific arguments for an expedition: namely, research in geography, oceanography, geology and natural history. Nordenskjöld gained the support of the king of Norway and Sweden, his patron Baron Oscar Dickson and a rich Russian merchant. In 1878, Nordenskjöld sailed from Tromsö in the

357-ton steam and sailing ship *Vega* with scientists from five nations. Sailing close to the coast, and encountering little ice, the *Vega* made good progress. Off the mouth of the Yenesey River he found a secure island anchorage, which he named Dickson Island after his Swedish patron. He correctly prophesied that the anchorage would "... one day be of great importance for commerce of Siberia" (Nordenskjöld 1882, p. 145). The site is the modern port of Dickson. By late fall, *Vega* came within 200 km of Mys Dezhneva before becoming beset by winter ice. In July, the following year, she sailed through Bering Strait. Nordenskjöld did not discover any new land, but we mention his multidisciplinary, multinational voyage because it marked a resurgence of Arctic Ocean research. Since Phipps' expedition 100 years earlier, polar research had been nearly eclipsed by the attention given to geographical exploration and national prestige.

In 1872, two young Austrian scientists, Navy Lieutenant Karl Weyprecht and Army Lieutenant Julius Payer, sailed into the Barents Sea on board the steamer *Tegethoff*. They were going to investigate the famous German geographer A.H. Petermann's claim of a relatively ice-free approach to the North Pole in this part of the Arctic Ocean - the revival of a 300-year old idea. Petermann's theories were not substantiated but the Austrians discovered and mapped part of the Franz Josef Land archipelago. Weyprecht and Payer put forward the hypothesis that this archipelago might be an outlier of a much greater landmass that included the North Pole. Weyprecht became convinced that scientific study should take precedence over geographical discovery in polar exploration. He began a personal campaign that led to the International Polar Year, 1882-1883, with 20 simultaneous expeditions in the polar regions, supported by 11 countries. None of these, however, was in the Arctic Ocean Basin.

In 1898, two expeditions attempted to sail into Nares Strait, Robert E. Peary aboard U.S.S. *Windward* and Otto Sverdrup aboard the Norwegian ship *Fram*. Peary's aim was the conquest of the Pole, whereas the Norwegians planned to explore and map the northern and northeastern coasts of Greenland. Ice prevented both ships from penetrating Kane Basin. Peary was obsessed by his desire to become the first to reach the Pole and achieve personal fame. Although Sverdrup had no intention of making a dash to the Pole, it was inconceivable, in Peary's view, that the Norwegians would not try, and he regarded Sverdrup's plans of exploration as an intrusion into "his" territory. The following summer, to prevent embarrassing complications, Sverdrup focused on exploration of western Ellesmere Island and the islands to the west, and sailed into Jones Sound. During the next three years, travelling by ship and by dog-team, the Norwegians accurately mapped that part of the Queen Elizabeth Islands now known as Sverdrup Islands (Norsk Videnskap-Akademi 1907-1919; Sverdrup 19893A,B, 1904). Per Schei, the geologist of the expedition, conducted reconnaissance geological surveys and established the first stratigraphic succession in the North American Arctic (Schei 1903). Peary, in turn, explored northern and northeastern Greenland, thereby settling any doubt about the insularity of Greenland (Hayes 1929).

Russian polar expeditions under the leadership of E. Toll, explored the New Siberian Islands between 1900 and 1903, and in 1913 the crews of two Russian vessels *Tamir* and *Vaigach* discovered and explored Severnaya Zemlya (Gorshkov 1980).

A new territorial awareness and interest in her northern frontiers felt by Canada led the Canadian government to sponsor a number of expeditions. In 1903 and 1904, A.P. Low of the Geological Survey of Canada sailed in the steam-powered *Neptune* into Hudson Bay, Smith Sound and Lancaster Sound, following which between 1906 and 1911, Captain J.E. Bernier in the D.G.S. *Arctic* visited many of the islands of the archipelago. The main objective of these expeditions was the establishment of sovereignty, but they also enabled Low in the *Neptune* and J.G. McMillan, geologist aboard *Arctic*, to study the geology of the regions traversed by the ships and produce the first regional geological maps of the Canadian Arctic Archipelago.

The Canadian Government, through its Geological Survey, also financed Vilhjalmur Stefansson's Canadian Arctic Expedition of 1913-1918. An ambitious program was devised in which a northern party, led by Stefansson, would search for new lands in the Beaufort Sea north of the already discovered islands of the archipelago, while a southern party, under the leadership of Dr. R.M. Anderson, would explore and carry out geological and biological field work along the mainland Arctic coast. The *Karluk*, the northern party's ship became trapped in the ice near Point Barrow and drifted westward, while Stefansson was hunting on the mainland. Stefansson and his men were unable to return, and *Karluk* drifted across the Chukchi Sea, eventually sinking near Herald and Wrangel islands in February 1914. Fewer than half the company of 28 survived. During this drift, the expedition's oceanographer, James Murray, obtained water depths, dredged bottom sediments and collected biological and water samples. The soundings were recorded in the ship's log and preserved but the samples sank with *Karluk*, and Murray's notes were lost with him when he attempted to reach the Siberian mainland on foot (personal communication, W.L. McKinley, 1980). Over the next four years, Stefansson discovered and mapped the remaining Queen Elizabeth Islands: including Brock, Borden, Mackenzie King, Meighen and Lougheed. Anderson, meanwhile, surveyed the southwestern islands of the archipelago, initiating a program of geological mapping that has continued, with some interruptions, to the present day. With Stefansson, the last major areas of unknown Arctic lands had been found, except for the surprising discovery from aircraft, after the Second World War, of previously unrecognized islands in Foxe Basin and Hudson Bay.

ACKNOWLEDGEMENTS

Useful in providing the historical setting for the growth of scientific knowledge of the Arctic Ocean areas are compilations by Kirwan (1959), who furnishes insights into the economic, strategic, political and personal motives behind many of the explorations; and the scholarly analyses, edited by Rey *et al.* (1984) tracing the development of geographic and scientific knowledge of the Arctic as a result of myths, conjectures, genuine discoveries and observations from antiquity to the eighteenth century. Figure 2 is reproduced by courtesy of the Royal Library, Copenhagen. We gratefully acknowledge permission from the National Archives of Canada to reproduce the map (Figures 3, 4).

REFERENCES

Barrow, J. 1818. A chronological history of voyages into the Arctic regions. London, John Murray. 379 pp.

Bernard R. 1976. The hollow earth. 2nd Edition. Citadel Press, New York. 225 pp.

Blom, G.A. 1984. The participation of the kings in the early Norwegian sailing to Bjarmeland (Kola Peninsula and Russian Waters), and the development of a royal policy concerning the northern waters in the Middle Ages. Arctic 37:385-388.

Bosworth, J. 1855. Description of Europa and the voyage of Othere and Wulfstan by King Alfred the Great. London, Murray. 80 pp.

Chevallier, R. 1984. Greco-Roman conception of the North from Pytheas to Tacitus. Arctic 37(4):341-346.

Falk, M.W. 1984. Images of pre-discovery Alaska in the work of European cartographers. Arctic 37(4):562-573.

Fisher, R.H. 1984. The early cartography of the Bering Strait region. Arctic 37(4):574-589.

Gorshkov, S.G. (Editor-in-chief). 1980. World ocean atlas, Volume 3: Arctic Ocean. Department of Navigation and Oceanography, Ministry of Defence, U.S.S.R., Pergamon Press, Oxford. 203 pp.

Hayes, J.G. 1929. Robert Edwin Peary, a record of his explorations, 1886-1909. Richards Tomlin, London. 448 pp.

Kane, E.K. 1856. Arctic explorations - the Second Grinnell Expedition in search of Sir John Franklin, 1853, 1854, 1855. Childs and Peterson, Philadelphia, Volume I, 464 pp.; Volume 2, 457 pp.

Keating, B. 1970. The hard death of Anian. In: The Northwest Passage; from the *Mathew* to the *Manhattan*. Edited by: B. Keating. Rand McNally and Company, Chicago. pp. 51-67.

Kirwan, L.P. 1959. The white road. A survey of polar exploration. Hollis and Carter, London. 374 pp.

Levere, T.H. 1988. Science and the Canadian Arctic, 1818-1876, from Sir John Ross to Sir George Strong Nares. Arctic 41:127-137.

Martin C. 1988. William Scoresby, Jr., (1789-1857) and the open polar sea - myth and reality. Arctic 41:39-47.

Nansen, F. 1911. In northern mists; Arctic exploration in early times. Heinemann, London. Volume I, 383 pp.; Volume II, 415 pp.

Nares, G. 1876. Captain Nares' report, communicated by the Lords Commissioners of the Admiralty, October 27th. Nature 15:24-28.

______. 1878. Narrative of a voyage to the Polar Sea during 1875-76 in H.M. Ships *Alert* and *Discovery*; with notes on the natural history edited by H.W. Feilden. Low, Marston, Searle & Rivington, London. Volume 1, 395 pp.; Volume 2, 378 pp.

Nordenskjöld, A.E. 1882. The voyage of the *Vega* around Asia and Europe with a historical review of previous journeys along the north coast of the Old World. Macmillan & Co., New York. 756 pp. (Translated from Swedish by Alexander Leslie).

Norsk Videnskaps-Akademi. 1907-1919. Report of the Second Norwegian Arctic Expedition in the *Fram* 1898-1902, issued in 36 numbers.

Raisz, E. 1948. General cartography. 2nd Edition. McGraw-Hill Book Co., New York. 354 pp.

Rey, L., C.R. Upton, and M. Falk. (Editors). 1984. Unveiling the Arctic. University of Alaska Press, Fairbanks. 292 pp. (Reprinted in Arctic 37:321-613).

Roots, E.F. 1986. Exclusive economic zones; a brief sketch of historical development and current issues. In: Exclusive Economic Zones; Advances in Underwater Technology. Ocean Science and Offshore Engineering 8:5-13.

Ross, J. 1819. A voyage of discovery, made under the order of the Admiralty, in his Majesty's ships *Isabella* and *Alexander* for the purpose of exploring Baffin Bay, and inquiring into the possibility of a Northwest Passage. Murray, London. 425 pp.

Royal Society. 1782. Minutes, Royal Society of London, Volume 6 (1769-1782).

Sabine, E. 1821. An account of experiments to determine the acceleration of the pendulum in different latitudes. Philosophical Transactions of the Royal Society, London. pp. 163-190.

Saladin d'Anglure B. 1980. Le syndrome chinois de l'Europe nordique ou la démesure de l''Amérasie entre le temps de l'Astrolalbe (1480) et l'espace du chronomètre (1780). l'Ethnographie 76:81-82.

Savelle, J.M. and C. Holland. 1987. John Ross and Bellot Strait: personality versus discovery. Polar Record 23:411-417.

Schei, P.E. 1903. Summary of geological results (of The Norwegian Polar Expedition in the *Fram* 1898-1902). Geographical Journal 22:55-65.

Scoresby, W., Jr. 1818. On the Greenland or polar ice. Memoirs, Wernerian Natural History Society, Edinburgh. Volume 2, pp. 261-338.

Smith, D.M. 1877. Arctic expeditions from British and foreign shores; from the earliest times to the expedition of 1875-76. Liddell, Glasgow and Melbourne. 824 pp.

Sverdrup, O.N. 1903A. The Second Norwegian Polar Expedition in the *Fram*. Scottish Geographical Magazine 19:337-353.

______. 1903B. The Norwegian Polar Expedition in the *Fram* 1898-1902. Geographical Journal 22:38-55.

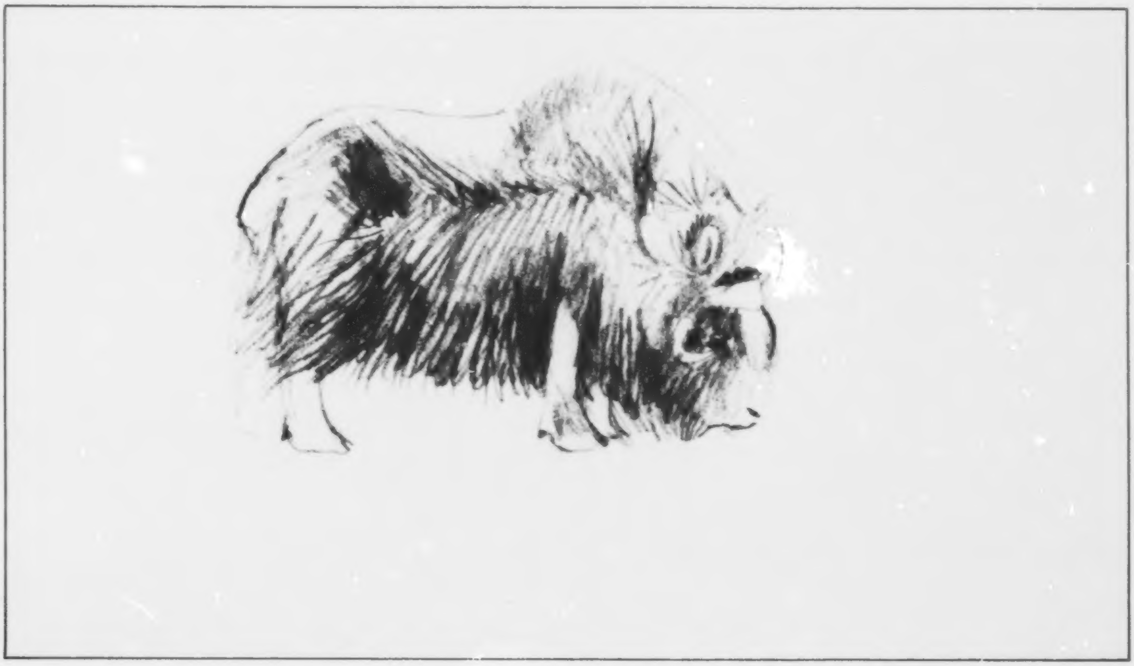
Sweet H. (Editor). 1883. King Alfred's Orosius. Early English Text Society, (London) Paper 79:1-42.

Taylor, A. 1955. Geographical discovery and exploration in the Queen Elizabeth Islands. Canada, Geographical Branch, Memoir 3:1-172.

Theutenberg, B.J. 1984. Mare clausum et mare liberum. Arctic 37(4):481-492.

Wallis, H. 1984. England's search for the northern passages in the sixteenth and early seventeenth centuries. Arctic 37(4):453-472.

Weber, J.R. and E.F. Roots. 1989. Historical background: exploration, concepts and observations. In: Decade of North American Geology, Volume L, Chapter 2. Edited by: G.L. Johnson, A. Grantz, and J.F. Sweeney. Geological Society of America, Boulder, Colorado.



Illustrated by Brenda Carter

EMILE FRÉDÉRIC DE BRAY AND HIS ROLE IN THE ROYAL NAVY'S SEARCH FOR FRANKLIN, 1852-1854

William Barr[1]

Abstract: In April 1852, Sir Edward Belcher's squadron, consisting of Assistance, Pioneer, Resolute, Intrepid and North Star, sailed from England in the continuing search for Sir John Franklin's expedition aboard Erebus and Terror, missing in the Arctic since the summer of 1845. One of the officers aboard Resolute, commanded by Captain Henry Kellett was a Frenchman, Enseigne de vaisseau Emile Frédéric de Bray, seconded at his own request from the French Navy to take part in the search.

Resolute and Intrepid wintered off Dealy Island near the mouth of Bridport Inlet, Melville Island. Prior to the onset of winter, De Bray led a sledge party west to Cape Providence to lay a depot for the following spring's sledge journeys. In the spring of 1853 he was leader of a sledge party which made a much longer journey north across Melville Island and west along its north coast in support of Captain Leopold McClintock. De Bray turned back at Cape De Bray on the northwest coast of Melville Island; he and his men sledged 594 km in 45 days.

The two ships sailed eastward in August 1853 but were soon beset again off Cape Cockburn, the southwest tip of Bathurst Island. After a second wintering, on orders from Sir Edward Belcher Resolute and Intrepid were abandoned in the spring of 1854, all the officers and men retreating to North Star at Beechey Island. During this latter operation De Bray led a sledge party of invalids which covered the 280 km distance in 17 days. He returned to England safely aboard the supply ship Phoenix in October 1854. For his part in the Franklin search De Bray was made an officer of the Legion d'Honneur by Napoleon III. He was also awarded the Arctic Medal by Queen Victoria. He was thus the only living Frenchman to receive that honour, although his better-known compatriot Joseph-René Bellot was awarded it posthumously.

Résumé: En avril 1852, l'escadre de Sir Edward Belcher, formée des navires Assistance, Pioneer, Resolute, Intrepid et North Star, partait d'Angleterre à la recherche de l'expédition de Sir John Franklin à bord de l'Erebus et du Terror, disparue dans l'Arctique depuis l'été de 1845. À bord du Resolute commandé par le capitaine Henry Kellett, il y avait parmi les officiers un Français, l'enseigne de vaisseau Èmile Frédéric de Bray, détaché à sa demande de la marine français pour prendre part à la recherche.

Les navires Resolute et Intrepid passèrent l'hiver au large de l'île Dealy, près de l'embouchure de l'inlet Bridport sur l'île Melville. Avant l'arrivée de l'hiver, de Bray mena une expédition en traîneau vers l'ouest jusqu'au cap Providence, dans le but d'établir de dépôt pour les expéditions en traîneau du printemps suivant. Au printemps de 1853, il conduisit une expédition en traîneau, dont l'itinéraire, beaucoup plus long, traversait l'Île Melville vers le nord et suivait sa côte nord vers l'ouest, afin d'assister le capitaine Léopold McClintock. De Bray fit demi-tour au Cap De Bray sur la côte nord-ouest de l'île Melville; ses hommes et lui avaient, en traîneau, parcouru 594 km en 45 jours.

Les deux navires prirent la mer vers l'est en août 1853, mais furent bientôt, à nouveau, aux prises avec des difficultés au large du Cap Cockburn, à la pointe sud-ouest de l'île Bathurst. Après un deuxième hiver, le Resolute et l'Intrepid furent abandonnés, sur les ordres de Sir Edward Belcher, au printemps de 1854, et tous les officiers et hommes d'équipage regagnèrent le North Star à l'île Beechey. Pendant cette dernière opération, de Bray mena une expédition en traîneau des invalides, qui couvrit 280 km en 17 jours. En octobre 1854, il regagna l'Angleterre, sain et sauf, à bord du ravitailleur Phoenix. Pour sa participation aux recherches pour retrouver Franklin, de Bray fut fait officier de la Légion d'honneur par Napoléon III. La Reine Victoria lui décerna également une récompense: l'"Arctic Medal". Il fut donc le seul Français vivant à recevoir cet honneur, bien que son compatriote mieux connu, Joseph-René Bellot, l'ait reçu à titre posthume.

On 15 April 1852, as Sir Edward Belcher's Arctic Squadron, consisting of the sailing vessels *Assistance*, *Resolute*, and *North Star* and the steamships *Pioneer* and *Intrepid* were heading down the river from Woolwich Basin to Greenhithe, Lieutenant George Strong Nares, a young officer aboard Captain Henry Kellett's ship *Resolute* was hurriedly writing a final note to his father. In the middle of a paragraph containing initial impressions of his fellow officers Nares included the following intriguing and typically ethnocentric remark: "The Frenchman does not seem an Englishman, but I suppose he will improve on acquaintance" (Nares 1852). Since the Frenchman is not named in the letter the casual reader is left wondering who he was and whether he did indeed "improve on acquaintance".

---

[1] Department of Geography, University of Saskatchewan, Saskatoon, Saskatchewan S7N 0W0

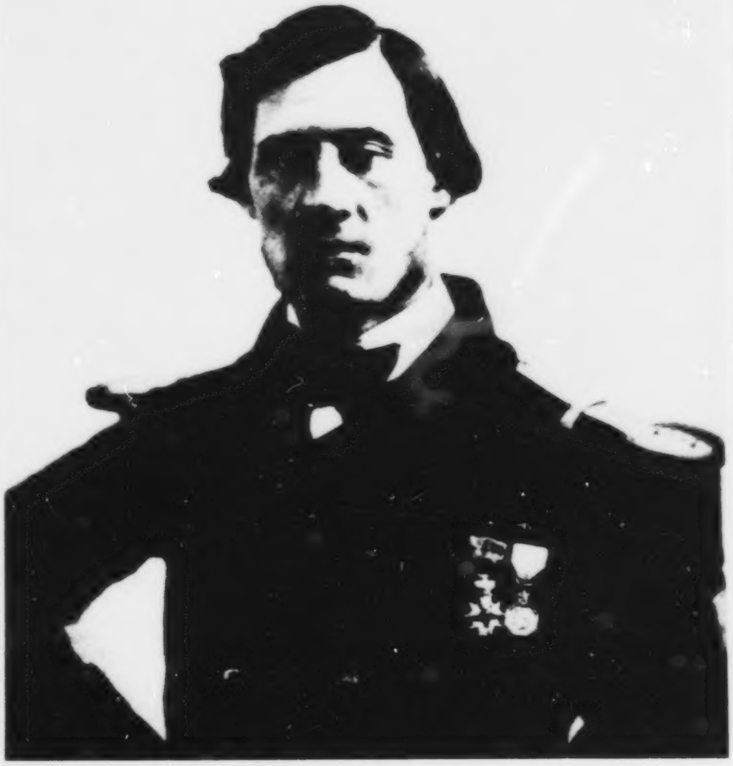
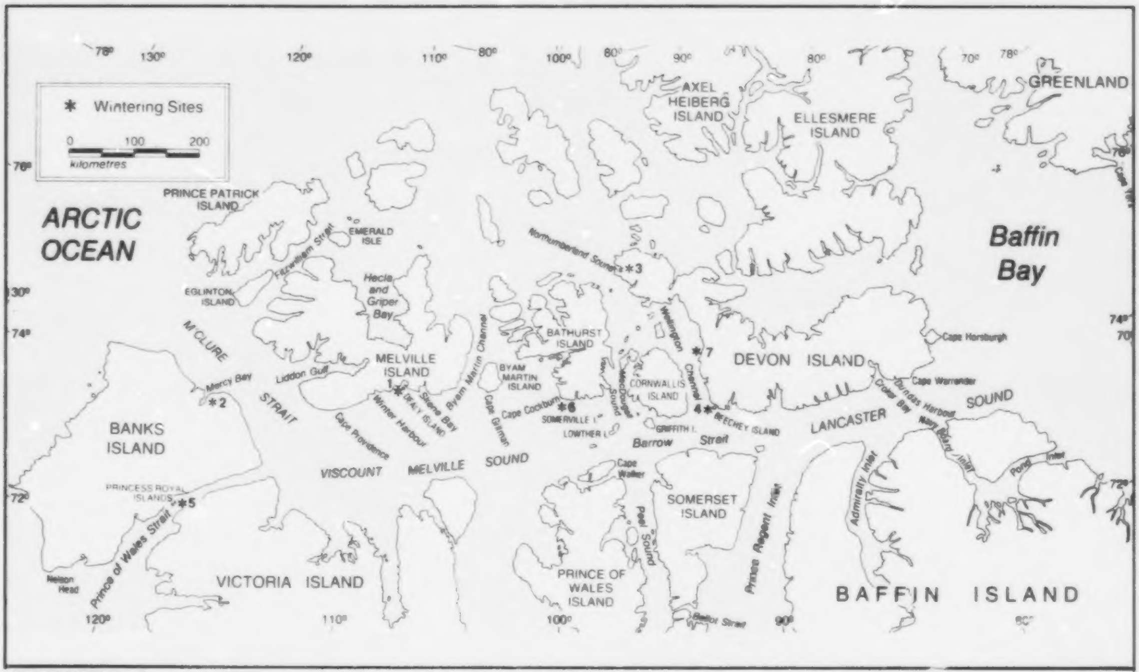


FIGURE 1: Emile Frédéric de Bray, soon after his return from the Arctic. Photo courtesy of Archives de France.

The Frenchman was Enseigne de vaisseau Emile Frédéric de Bray (Figure 1). Born in Paris on 9 March 1829, Emile de Bray was enrolled as a cadet at the École Navale on 1 October 1844. He graduated as Élève de la Marine on 1 August 1846, when he was posted to Brest (De Bray, G., n.d.). On 1 October he joined the corvette *Galathée* and served in the Pacific for the next three years. Returning to Lorient aboard *Galathée* on 17 September 1849, over the next 18 months De Bray served as "aspirant" aboard six vessels, visiting places such as Toulon, Civita Vecchio and Naples. Having passed the requisite examination on 2 April 1851, De Bray was promoted to the rank of Enseigne de vaisseau.

In 1850 the mounting concern in Britain and elsewhere as to the fate of Sir John Franklin's ships *Erebus* and *Terror*, which had disappeared while engaged in a search for the North-West Passage in 1845, resulted in a series of parallel and overlapping expeditions heading into Barrow Strait. Totalling 11 ships, they included one American expedition and both Royal Navy and private British endeavours. Probably the most significant result of this multi-faceted search, all of whose components focused their attention on Wellington Channel and Cornwallis Island, was the discovery that Franklin's ships had spent the winter of 1845-



✱ Wintering Sites
0 100 200
kilometres
ARCTIC OCEAN
PRINCE PATRICK ISLAND
EMERALD ISLE
Fitzwilliam Strait
Hecla and Griper Bay
EGLINTON ISLAND
M'CLURE STRAIT
Mercy Bay
✱2
BANKS ISLAND
Liddon Gulf
MELVILLE ISLAND
1
Winter Harbour
Cape Providence
Skene Bay
Byam Martin Channel
BYAM MARTIN ISLAND
Cape Gillman
Cape Cockburn
✱6
BATHURST ISLAND
SOMERVILLE I.
LOWTHER I.
CORNWALLIS ISLAND
GRIFFITH I.
Barrow Strait
Wellington Channel
✱7
4✱
BEECHEY ISLAND
DEVON ISLAND
Northumberland Sound
✱3
AXEL HEIBERG ISLAND
ELLESMERE ISLAND
GREENLAND
Baffin Bay
Cape Horsburgh
Cape Warrender
Dundas Harbour
Croker Bay
LANCASTER SOUND
Admiralty Inlet
Navy Board Inlet
Pond Inlet
VISCOUNT MELVILLE SOUND
PRINCESS ROYAL ISLANDS
✱5
Prince of Wales Strait
Nelson Head
VICTORIA ISLAND
Cape Walker
SOMERSET ISLAND
Peel Sound
Prince Regent Inlet
PRINCE OF WALES ISLAND
Bellot Strait
BAFFIN ISLAND
78°
130°
120°
110°
100°
90°
80°
70°
76°
74°
72°

FIGURE 2: Part of the Canadian Arctic Islands, showing the areas of operations and wintering sites of the search expeditions of 1850-1854. 1. Resolute and Intrepid, 1852-1853; 2. Investigator, 1851-1853; 3. Assistance and Pioneer, 1852-1853; 4. North Star, 1852-1854; 5. Investigator, 1850-1851; 6. Resolute and Intrepid, 1853-1854; 7. Assistance and Pioneer, 1853-1854.

1846 at Beechey Island near the southwestern corner of Devon Island (Figure 2) (Sutherland 1852, pp. 303-308; Kane 1854, pp. 162-165; Osborn 1852, p. 109). Among the evidence left by Franklin's party were the graves of three of his men. But the most baffling and frustrating aspect was that not the slightest trace of any record or note was found. The movements of the missing ships after they left Beechey Island, presumably in the summer of 1846, were still a complete mystery.

News of the discovery at Beechey Island reached Britain in October 1850 (Snow 1851). In the light of this information, a further expedition sponsored by Lady Franklin and led by William Kennedy sailed from Aberdeen aboard *Prince Albert* in May 1851 (Kennedy 1853; Bellot 1854, 1855). Significantly the second-in-command was Lieutenant de vaisseau Joseph-René Bellot, who had obtained special leave from the French Navy to participate in the expedition. It was also in the light of the discoveries at Beechey Island that a further Royal Navy expedition was dispatched, under command of Sir Edward Belcher. As we have seen, it consisted of five ships.

Probably De Bray's imagination was fired by Bellot's participation in the expedition aboard *Prince Albert*. On learning of the plans to dispatch Sir Edward Belcher's squadron in the summer of 1852, De Bray decided to try to participate, his opening gambit being a letter requesting permission to offer his services to the British Admiralty, addressed to the Minister of the Navy and the Colonies and dated 20 December 1851. His request was forwarded to the British Admiralty who in turn approved it. On 20 January 1852 the British Foreign Minister, Earl Granville, wrote to Count Walewski, the French Ambassador, that De Bray would be allowed to participate in the expedition.

Over the next few months the details were worked out, and on 13 April 1852 De Bray left Paris for London. Thus De Bray came to be aboard *Resolute* as the squadron moved down the Thames on 15 April. After a number of official visits the five-ship squadron finally sailed from the Nore on the afternoon of 22 April, accompanied by the steamers *Basilisk* and *Desperate*, which were to escort the squadron for the first part of the Atlantic crossing.

On 25 April the squadron was lying at anchor off Stromness in the Orkneys. De Bray had started to get to know his fellow officers whom he found "very obliging, since I had only an imperfect command of English, and understanding me required a great deal of good will (De Bray n.d., p. 9). On the 27th, accompanied by Lieutenants Hamilton, Pim and Nares he made an excursion by carriage to Kirkwall where they visited the cathedral.

The squadron set out again on 28 April, *Desperate* and *Basilisk* towing the sailing vessels, so that *Pioneer* and *Intrepid* could conserve fuel. Over the next few days the towlines parted frequently in rough seas and it was not until the 8 May that the squadron reached 20°W where, by prearrangement, *Desperate* and *Basilisk* turned back.

The first ice was sighted on the 20th, some 13 km off Cape Desolation, and on the 24th the coast of Greenland near Godthåb was in view. On the 28th the squadron dropped anchor off Kron Prins Ø, and De Bray met Inuit for the first time. He was greatly impressed by their skill in kayak-rolling and their marksmanship with harpoons, but was nauseated by the stench inside their half-buried houses. The next stop was at Lievely on Disko Ø, where De Bray took the opportunity to climb a snow-capped mountain overlooking the harbour. After a further stop at Upernavik the squadron pushed north along the Greenland coast, encountering increasingly heavy ice. On the evening of 26 June *Resolute* was severely nipped between two floes; since the shuddering of the ship was sufficient to start all her bells ringing, the incident clearly made quite an impression on De Bray. The only damage sustained was a smashed rudder. Once the pressure slackened, the crews cut ice-docks and De Bray has left a detailed description of the technique involved.

On 30 June the Royal Navy squadron came up with a fleet of 14 whaling ships, and De Bray witnessed the crushing and sinking of the American whaler *McLellan*. Throughout June, in company with the whalers, the Navy vessels made fitful progress northward across Melville Bugt, exploiting leads and polynyas whenever possible, mooring to ice anchors or lying in ice-docks when the ice was treacherous.

On the morning of 1 August *Resolute*, *Intrepid*, *North Star* and the whaler *Alexander* moored to fast-ice off Kap York, and De Bray was a member of the party that walked ashore to meet the local Inuit. Before returning to the ship, De Bray climbed to the summit of Kap York in the hope of sighting *Assistance* and *Pioneer*, but without success. That evening *Alexander* parted from the Navy ships, taking their last mail, while *Resolute*, *Intrepid* and *North Star* headed west across the North Water. They sighted Cape Horsburgh on 3 August, then swung west into the mouth of Lancaster Sound. Coasting west past Croker Bay, De Bray made perceptive comments on the landforms of this striking coastline:

> "... the summits of the mountains are all in the same horizontal plane, cut here and there by deep gullies. The slopes of the mountains drop almost sheer into the sea and from a certain distance have quite a strong resemblance to the bastions of a fortress." (De Bray n.d., p. 48)

In the early hours of the 11th, *Resolute* and *Intrepid* dropped anchor alongside *North Star* off Beechey Island. Later in the morning De Bray took a stroll ashore, examining Sir John Ross's yacht *Mary*, the graves of the three members of Franklin's expedition, assorted debris scattered around the wintering site and the sledge-tracks in the gravel first spotted by Captain Erasmus Ommanney's party in 1850. On his way back from Union Bay (Figure 3) De Bray climbed to the summit of Beechey Island, and in one of three cairns there found notes left by Captains Austin and Ommanney in 1850.

Next day while *Resolute* loaded provisions from *North Star*, De Bray undertook an even more ambitious hike. He climbed to the summit of Cape Riley where he built a cairn surmounted by a pole to which he nailed a board with the carved inscription "H.M.S.

Résolue 11 Août 1852" on one side and his initials "E.D.B." on the other. At the foot of the cape he found a cairn containing notes signed by Captains Austin, De Haven and Griffith, and a short distance away a red-painted cross with the inscription "Prince Albert 25 August 1851".

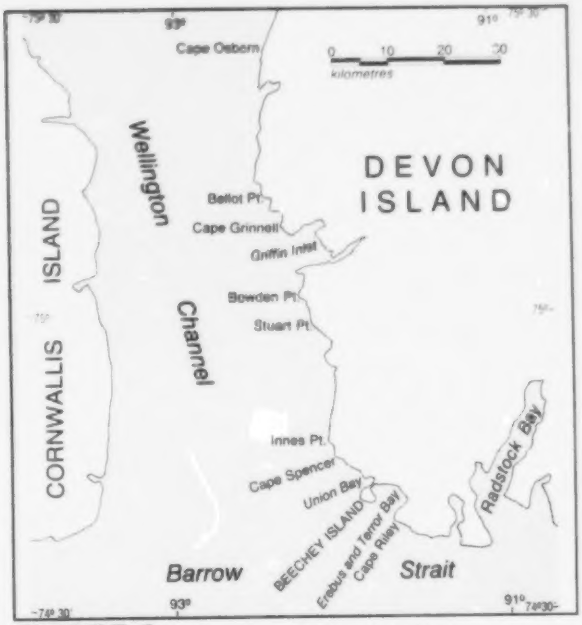

75°30'
93°
91°
75°30'
Cape Osborn
0
10
20
30
kilometres
DEVON
ISLAND
Wellington
Channel
CORNWALLIS ISLAND
Bellot Pt.
Cape Grinnell
Griffin Inlet
Bowden Pt.
Stuart Pt.
75°
75°
Innes Pt.
Cape Spencer
Union Bay
BEECHEY ISLAND
Erebus and Terror Bay
Cape Riley
Radstock Bay
Barrow
Strait
74°30'
93°
91°
74°30'

FIGURE 3: Map of the Beechey Island area.

When *Assistance* and *Pioneer* had arrived at Beechey Island and the other four ships had coaled and provisioned from *North Star* (which was to remain at Beechey Island as a depot ship), the squadron dispersed. On 14 August *Assistance* and *Pioneer* started north up Wellington Channel. At noon next day *Resolute* and *Intrepid* (Captain Leopold McClintock) set off westward for Winter Harbour (Figure 2) with orders to establish a major depot for *Investigator* (Captain Robert M'Clure) and/or *Enterprise* (Captain Richard Collinson) which had entered the Arctic Ocean via Bering Strait, also in search of the Franklin expedition, and had not been heard from for two years.

Having left a depot and a whaleboat at Cape Hotham on Cornwallis Island, the ships pushed on west to Assistance Harbour on Griffiths Island. Here *Resolute* ran heavily aground near the top of the tide; to make the situation even worse she was caught by a large drifting floe some 10 km^2 in area and heeled violently to starboard. She was finally refloated at the cost of about half of her false keel. Next day (17 August) De Bray was a member of a party which built a cairn and left documents on the southern tip of Griffiths Island. After waiting off Lowther Island for about 10 days for ice conditions to improve, the two ships finally continued west on the 28th. Having left depots on southern Bathurst Island and southeastern Melville Island (where several muskoxen were shot), the expedition reached Winter Harbour (Figure 4) on 7 September. A depot was landed near Parry's Rock.

Unfortunately, since solid ice in Winter Harbour precluded its use as winter quarters, Kellett decided to backtrack to Dealy Island, off Bridport Inlet. A suitable wintering site

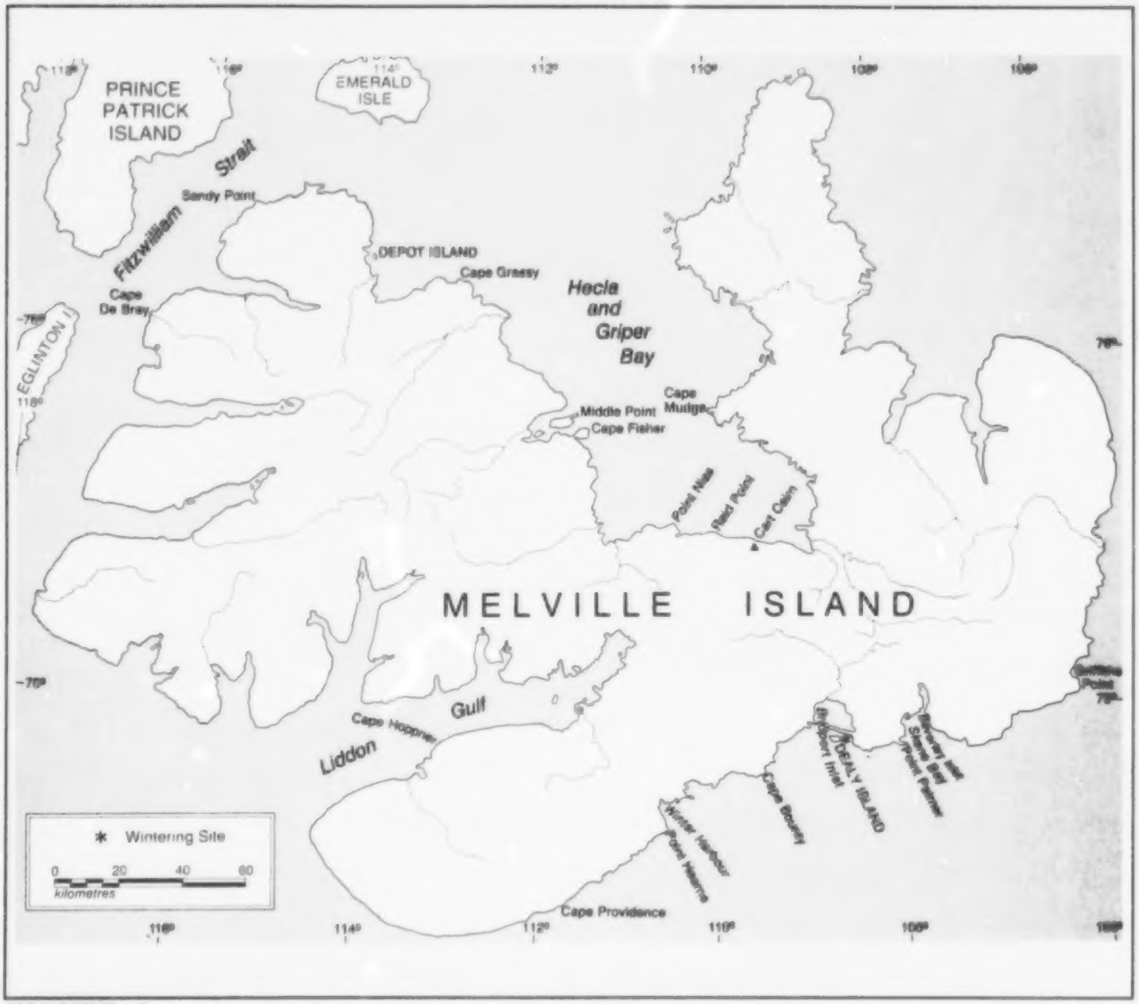

PRINCE PATRICK ISLAND
EMERALD ISLE
Fitzwilliam Strait
Sandy Point
DEPOT ISLAND
Cape Grassy
Cape De Bray
EGLINTON I.
Hecla and Griper Bay
Cape Mudge
Middle Point
Cape Fisher
Point Nias
Reid Point
Cape Cairn
MELVILLE ISLAND
Liddon Gulf
Cape Hoppner
Griffiths Point
Bridport Inlet
DEALY ISLAND
Skene Bay
Point Palmer
Cape Bounty
Winter Harbour
Point Hearne
Cape Providence
Wintering Site
0
20
40
60
kilometres
118°
116°
114°
112°
110°
108°
106°
76°
75°
118°

FIGURE 4: Map of Melville Island showing area covered by De Bray's sledge trips.

was found off the east side of the island and on the 9th work began on cutting docks for the ships in the edge of the fast-ice. Normal preparations for an arctic wintering began: sails were unbent and stowed in their lockers; the decks were enclosed by tents, and the ships' boats were moved ashore to Dealy Island.

On 22 September five sledge parties set off in different directions to lay depots for the main sledging operations the following spring. De Bray, in command of the sledge "Marie" with a crew of six, was to accompany Lieutenant Pim in taking supplies westward along the south coast of Melville Island for parties that would cross to Banks Island the following spring. They reached their destination, Cape Providence, safely on 2 October and cached the supplies. On the way back, on 3 October Pim and De Bray shot a muskox, so muskox steaks were on the menu that night. He pronounced it "... the most delicious meat I have ever eaten, although a little tough" (De Bray n.d., p. 77). The two sledge parties reached the ships on 8 October having covered 244 km in 17 days (including a day tentbound by bad weather).

On the morning of 14 October De Bray was taking a stroll on Dealy Island when he sighted a sledge approaching from the west. It was Lieutenant Mecham's party with exciting news; having established his depot at Cape Hoppner on Liddon Gulf as arranged, on his return Mecham had decided to visit Parry Rock. There, in a cylinder on top of the rock he found a message left by Captain Robert M'Clure of *Investigator* the previous April. The message gave a brief précis of *Investigator's* activities since passing through Bering Strait in July 1850. When the message had been left at Parry Rock, *Investigator* had just spent a winter at Mercy Bay on northern Banks Island. The message ended with the information that, if the ice permitted, M'Clure intended to sail eastward to Baffin Bay in the summer of 1852. Since Kellett's expedition had seen no sign of *Investigator*, it was assumed that she was still at Mercy Bay, so Kellett decided to send a rescue party there in early spring.

On 17/18 October De Bray was a member of a hunting party to the head of Bridport Inlet. However, the weather was foul and they returned empty-handed. This in fact was the last hunting trip of the season. Game killed on Melville Island in the fall included 27 muskoxen, 5 caribou, 23 hares, 39 ptarmigan, 1 bear, 1 wolf, 1 fox and 2 lemmings (De Bray n.d., p. 91).

On returning to the ships, the hunting party heard the sad news of the expedition's first death: Walter Moberly, *Resolute's* steward, had died of a heart attack on the 18th. On the 26th the body was sledged ashore at the head of a funeral procession and was buried in a shallow grave piled high with rocks and earth. An oak headboard 90 cm high was erected.

Preparations for the wintering continued. The decks were insulated with a mixture of fine gravel and snow, packed down in a layer 22 cm deep. Snowblocks were built up around the ships' sides to reduce heat loss (Figure 5). On 4 November the upper rim of the sun appeared briefly above the southern horizon at noon for the last time. Winter had now begun and with it the traditional winter activities. Classes in subjects such as navigation, as well as the basics of reading and writing, were offered by various officers, and

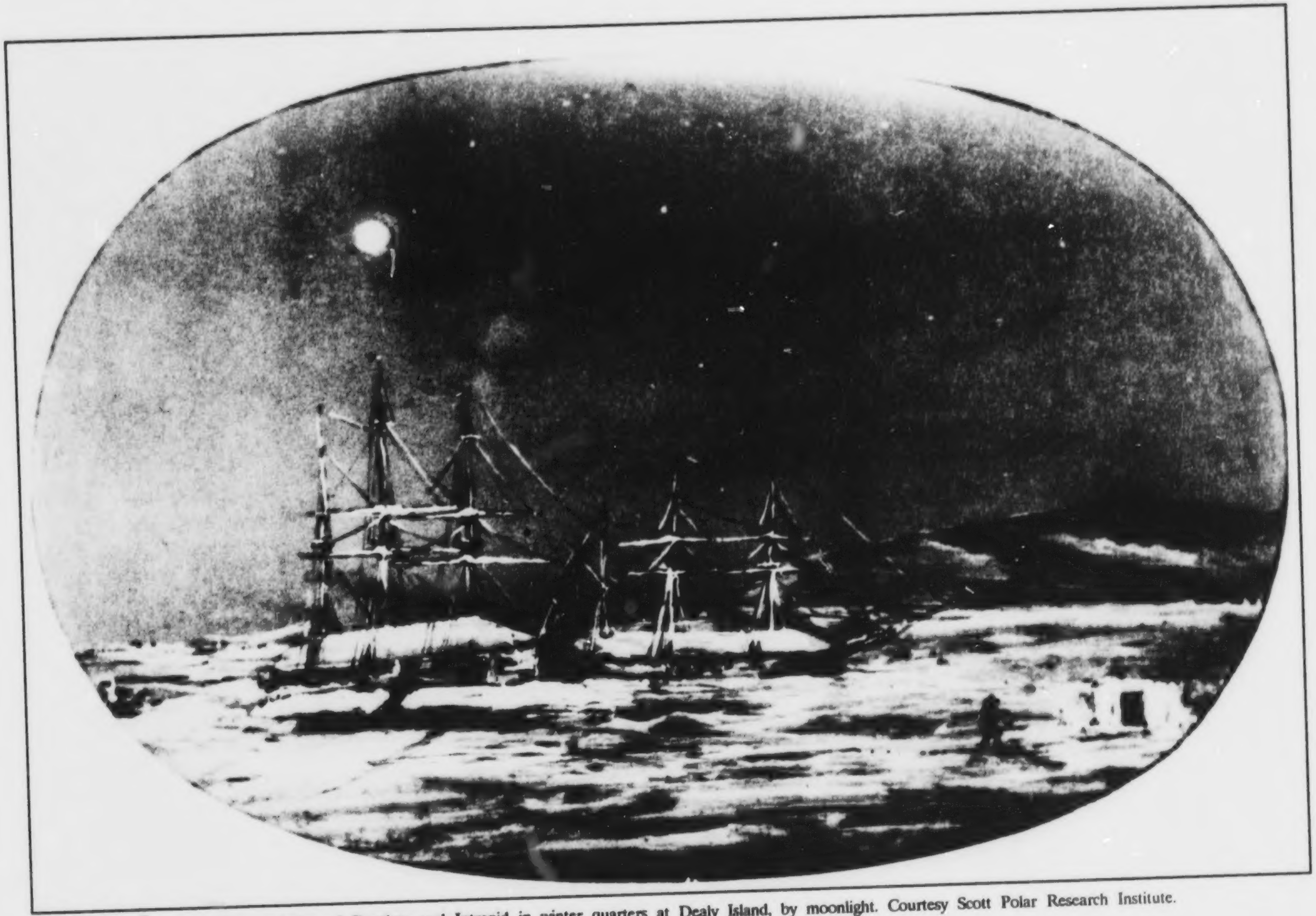


FIGURE 5: De Bray's painting of Resolute and Intrepid in winter quarters at Dealy Island, by moonlight. Courtesy Scott Polar Research Institute.

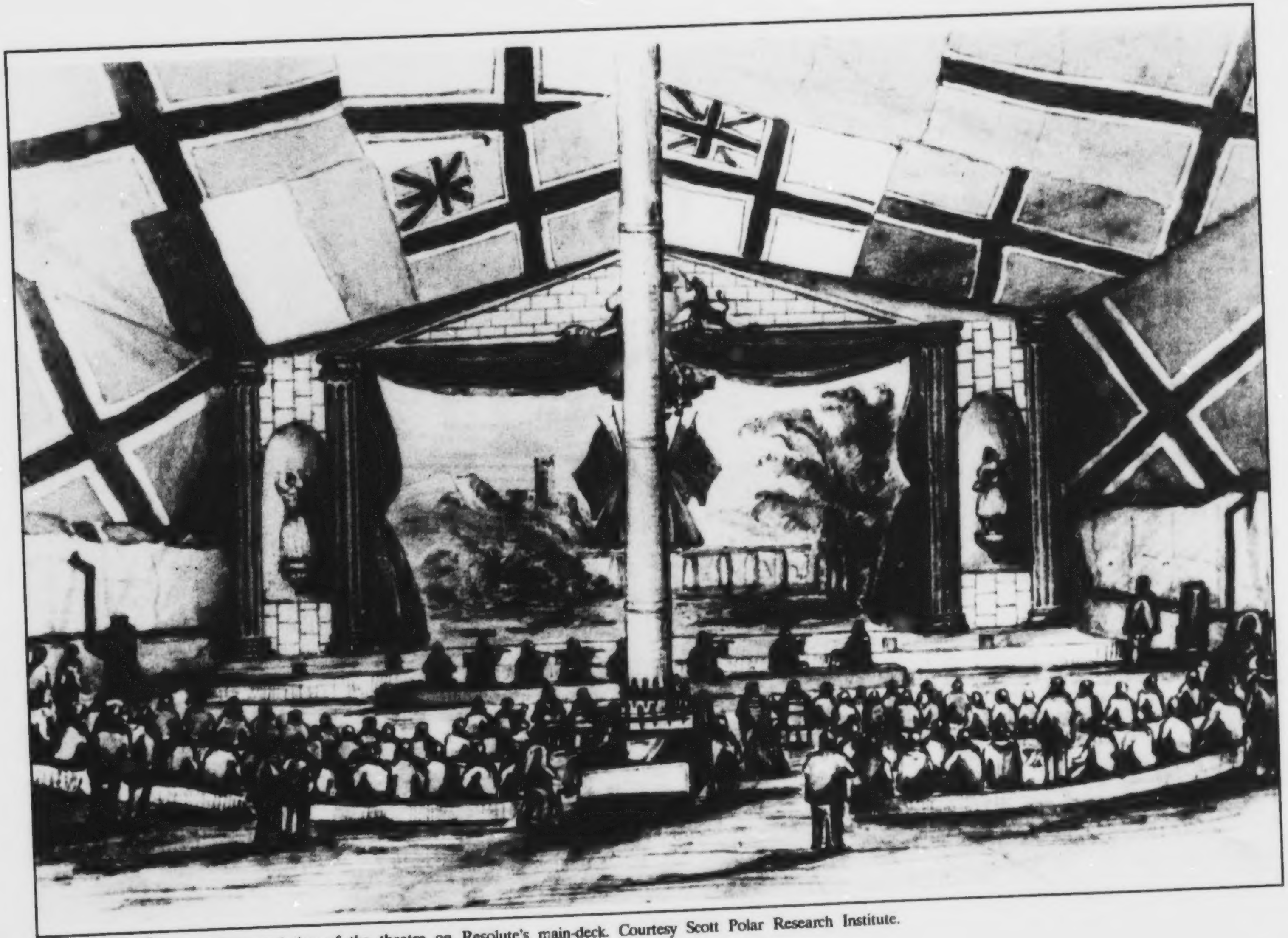


FIGURE 6: De Bray's painting of the theatre on Resolute's main-deck. Courtesy Scott Polar Research Institute.

preparations began for the first theatrical performance. This was held on the night of 23 November on *Resolute's* housed-in main-deck (Figure 6). Two stoves managed to raise the temperature to -5°C from the outside temperature of -9°. The officers presented an historical drama, "Charles II" for which De Bray sewed one of the ladies' costumes; he was also responsible for make-up. The men then presented a farce entitled "Who speaks first" but it had to be discontinued when one of the principals got too drunk to play his part.

The beneficial effect of this activity must have been dampened when a second death occurred on 12 December. George Drover, one of *Intrepid's* men became ill after one of the fall sledge trips. He too was buried on Dealy Island, the funeral service being held on the 19th. Although it took place at noon, Captain Kellett needed a lantern to read the service.

Christmas and New Year's were celebrated with appropriate festivities. Muskox, hare, ptarmigan and caribou were served for Christmas dinner; De Bray decided that the caribou was "... the most delicious venison I have ever tasted" (De Bray n.d., p. 101). He also visited the crew's Christmas dinner in the orlop deck and seems to have been startled by the scene: "For a moment one could hear only the noise of knives and forks; at the end of ten minutes the astonished eye had nothing left to contemplate but a vast field of carnage" (De Bray n.d., p. 100).

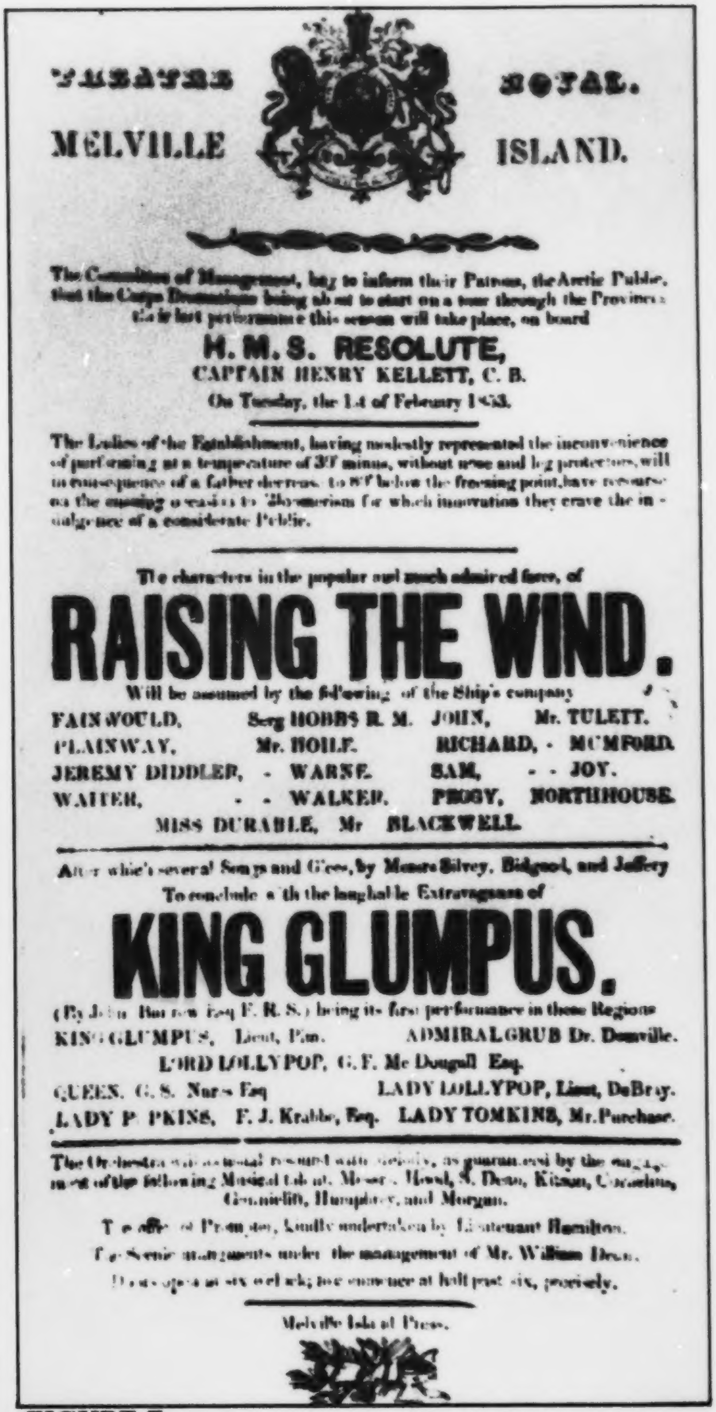
In the New Year work began on the Dealy Island depot. On 9 January three two-tonne tanks were swayed out of the hold and sledged ashore to the south point of the island. Filled with provisions, they were to become an integral part of the depot. Thereafter sledging provisions ashore became one of the daily chores, the sledges hauling gravel for ballast on the return trip.

The second theatrical performance was held toward the end of January. This time De Bray was promoted to playing one of the female roles, that of 'Lady Lollipop' in a comedy called "King Glumpus", written in verse by Sir John Barrow (Figure 7). De Bray found the performance an ordeal: he was wearing satin slippers and his feet were half frozen; after the show he had to soak them in warm water to restore feeling.

The sun reappeared on 5 February and the tempo of outdoors work was intensified. Hauling and stowing of ballast was a major chore, while dog sledges began hauling sand from Dealy Island to spread on the ice along a strip from the ships towards the open sea, to encourage faster melting of the ice.

On 3 March two sledges commanded by Lieutenant Pim and Dr. Domville set off for Banks Island in order to make contact with *Investigator*. On the 21st other spring sledge parties were detailed and their routes outlined. De Bray was placed in charge of the sledge "Hero", which was to travel in support of McClintock across Melville Island, then west along the coast of Hecla and Griper Bay. Under his command were eight men from *Intrepid's* crew.

Seven sledges set off in various directions on the morning of 4 April. In company with McClintock's sledge, De Bray headed north across the "waist" of Melville Island. Progress was slow due to the numerous gullies, and only light snowcover on the rock-strewn plateau. The sledge crews reached Hecla and Griper Bay on the 12th, then headed northwest along the coast. Swinging around the northwest tip of Melville Island, on 2 May the two sledges reached a cape which McClintock named Cape



THEATRE ROYAL.
MELVILLE ISLAND.

The Committee of Management, beg to inform their Patrons, the Arctic Public, that the Corps Dramatique being about to start on a tour through the Provinces their last performance this season will take place, on board

H. M. S. RESOLUTE,
CAPTAIN HENRY KELLETT, C. B.
On Tuesday, the 1st of February 1853.

The Ladies of the Establishment, having modestly represented the inconvenience of performing at a temperature of 37° minus, without arms and leg protectors, will in consequence of a further decrease to 80° below the freezing point, have recourse on the ensuing occasion to Bloomerism for which innovation they crave the indulgence of a considerate Public.

The characters in the popular and much admired farce, of

RAISING THE WIND.

Will be assumed by the following of the Ship's company

FAINWOULD,	Serg HOBBS R. M.	JOHN,	Mr. TULETT.
PLAINWAY,	Mr. HOILE.	RICHARD,	- MUMFORD.
JEREMY DIDDLER,	- WARNE.	SAM,	- - JOY.
WAITER,	- - WALKER.	PEGGY,	NORTHHOUSE.
MISS DURABLE,	Mr BLACKWELL.		

After which several Songs and Glees, by Messrs Silvey, Bidgood, and Jeffery
To conclude with the laughable Extravaganza of

KING GLUMPUS.

(By John Barrow Esq F. R. S.) being its first performance in these Regions

KING GLUMPUS,	Lieut. Pim.	ADMIRAL GRUB	Dr. Domville.
LORD LOLLYPOP,	G. F. Mc Dougall Esq.		
QUEEN.	G. S. Nares Esq	LADY LOLLYPOP,	Lieut. DeBray.
LADY PIPKINS,	F. J. Krabbe, Esq.	LADY TOMKINS,	Mr. Purchase.

The Orchestra will as usual resound with melody, as guaranteed by the engagement of the following Musical talent, Messrs. Hood, S. Dean, Kitson, [illegible], Gunnicliff, Humphreys, and Morgan.

The office of Prompter, kindly undertaken by Lieutenant Hamilton.
The Scenic arrangements under the management of Mr. William Dean.
Doors open at six o'clock; to commence at half past six, precisely.

Melville Island Press.

FIGURE 7: Playbill produced on board Resolute for the second theatrical performance of the winter. Photo courtesy Scott Polar Research Institute.

De Bray (Figure 4). McClintock ordered De Bray to cache his load there and start for home, while he and his men headed west across the sea ice. On the way back De Bray was ordered to relay a depot forward for several days' march from Point Nias to Cape Fisher.

On the return trip De Bray made excellent progress since the sledge was light. He was even able to hoist a sail to take advantage of frequent favourable winds. But on 12 May, near Point Nias, a crisis occurred. One of the men, Coombes, who had stopped to relieve himself, suddenly dropped unconscious. De Bray did his best to revive him but without success. The man was dead. De Bray was now faced with a difficult decision, especially for a foreign officer not fully acquainted with the norms and expectations of the Royal Navy. His men wanted him to sledge the body straight back to the ship for proper burial, whereas his instructions specified that he should relay a depot forward from Point Nias to Cape Fisher for McClintock's use on his return trip. After deliberation he decided to accede to his men's wishes. On 18 May, sledge-flag flying at half mast, De Bray and his men returned to their ship.

Their sledge trip represented an impressive achievement. In 45 days they had covered 594 km. Taking into account days when they were weatherbound, this represented a mean daily distance of 15.74 km (12.14 on the outward trip and 19.36 on the homeward trip). From the evidence of the track-chart appended to De Bray's report to McClintock (Figure 8), he appears to have been a workmanlike surveyor. Deviations from the modern map are readily explicable in terms of the problems of low, snow-covered coastlines, indistinguishable from sea ice and often obscured by fog and/or blowing snow.

The varying reactions to De Bray's decision to sledge Coombes' body back to the ship rather than completing his tasks are interesting: McDougall, sailingmaster aboard *Resolute* felt that a British officer would have completed his orders then brought the body back (McDougall 1857, pp. 242-243). Most importantly for De Bray's peace of mind, however, both Captain McClintock and Captain Kellett approved of his decision. Coombes funeral was held on 22 May, the grave being located beside the other two on Dealy Island. De Bray led the funeral procession and the body was hauled on a sledge flying De Bray's sledging flag.

A great deal had happened at Dealy Island in De Bray's absence. As a result of Lieutenant Pim's journey, some 22 sick members of *Investigator's* crew had arrived at Dealy

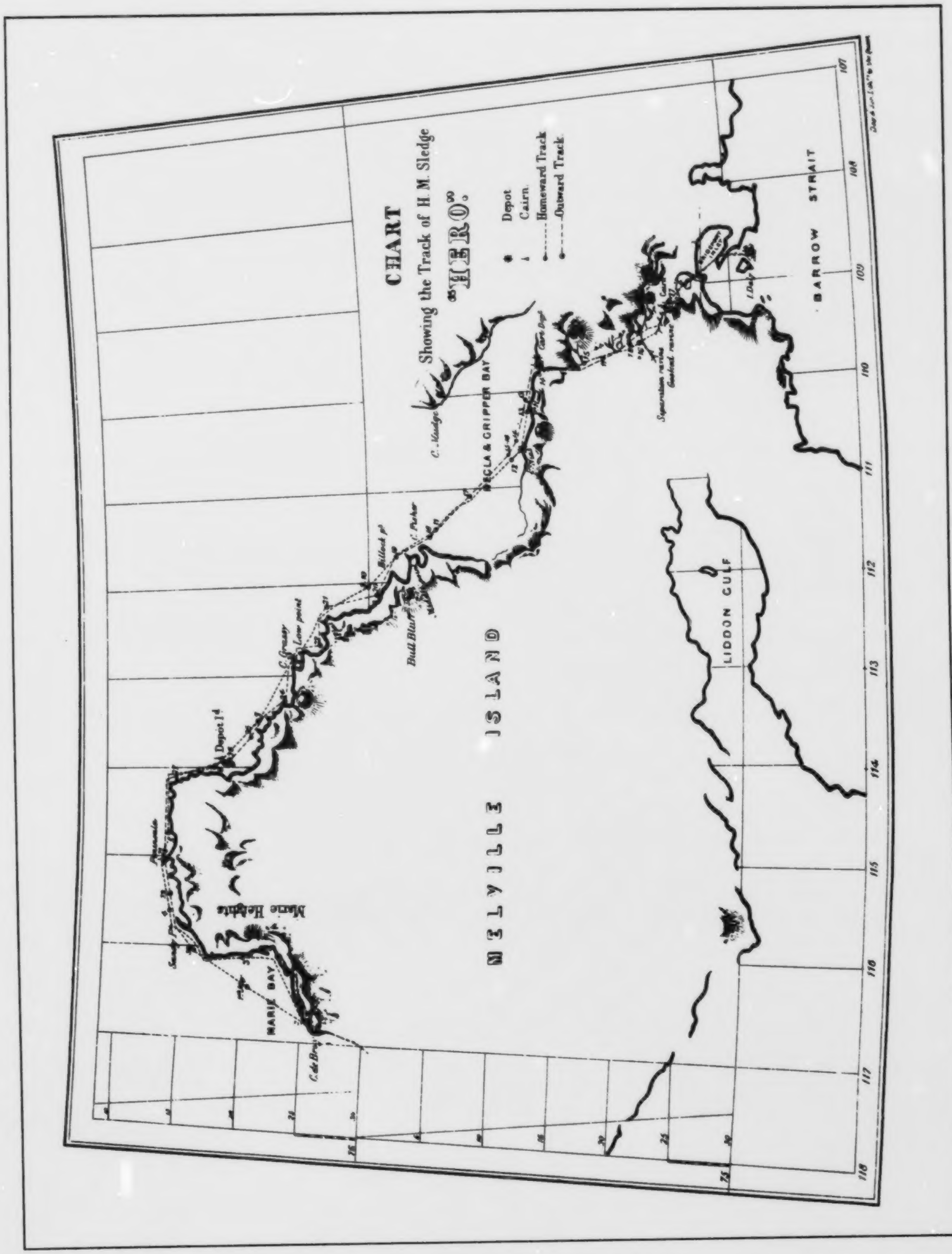


CHART
Showing the Track of H.M. Sledge
"HERO"
Depot
Cairn
Homeward Track
Outward Track
MELVILLE ISLAND
LIDDON GULF
BARROW STRAIT
HECLA & GRIPPER BAY
MARIE BAY
Marie Heights
C. de Bray
Depot 1st
C. Grassy
Low point
Bull Bluff
C. Parker
C. Mudge
107
108
109
110
111
112
113
114
115
116
117
118
75

FIGURE 8: De Bray's track-chart of his sledge trip to Cape De Bray.

Island, and to house them, *Intrepid* had been turned into a hospital ship. On 7 May the 10 least fit of these men, led by Lieutenant Creswell of *Investigator* had set off eastward for *North Star* at Beechey Island.

The day after De Bray's return, work began on the foundation of the store-house on Dealy Island. The structure grew steadily, but on 13 June it experienced a setback. Due to the wet nature of the ground and badly designed foundations the entire building collapsed and had to be rebuilt. On 17 June, while De Bray was hunting, the last of *Investigator's* men arrived from the west. As described by Miertsching (Neatby 1967, p. 200) it was a sorry-looking party: eight men were riding lashed on the sledges while others were leaning on the sledges or were supported by their companions. By now preparations for getting the ships ready for sea were in full swing, while a steady sledge traffic moved supplies ashore to the depot (Figure 9). During this period, the last of the sledge expeditions returned. Lieutenant Mecham arrived after an absence of 94 days, during which he had explored Liddon Gulf and the south coasts of Eglinton and Prince Patrick islands. On 18 July McClintock arrived after covering an amazing 1,660 km in 106 days. After parting from De Bray, McClintock had discovered and explored Prince Patrick Island, Eglinton Island and Emerald Isle (Figure 4).

The ice was starting to break up, and by 28 July *Resolute* was afloat again. The men now concentrated on setting up the running rigging and generally making the ships ready for sea. The storehouse on Dealy Island had been stocked with sufficient supplies for 60 men for a winter, in case the crew of *Enterprise* needed them. De Bray drafted a detailed plan of the depot and its contents and compiled an inventory of the contents of every cask and tank (Figure 10). Some of these supplies were still in the building when it was partially excavated and restored in 1978 (Janes 1982). In addition, a cairn 9 m-high, surmounted by a mast had been built on the summit of Dealy Island.

During a gale on the night of 17/18 August the ice began to break up in spectacular fashion; the floe to which the ships were moored began to drive rapidly southwards. Break-up was so sudden and the weather so wild that a pump used for watering the ships, and a small boat were left on shore. After a little work the ships got free of the ice and pitched and rolled with the waves for the first time in months.

They managed to reach Point Griffiths on southeastern Melville Island without much difficulty, but there they encountered ice. Until 10 September the ships were able to make

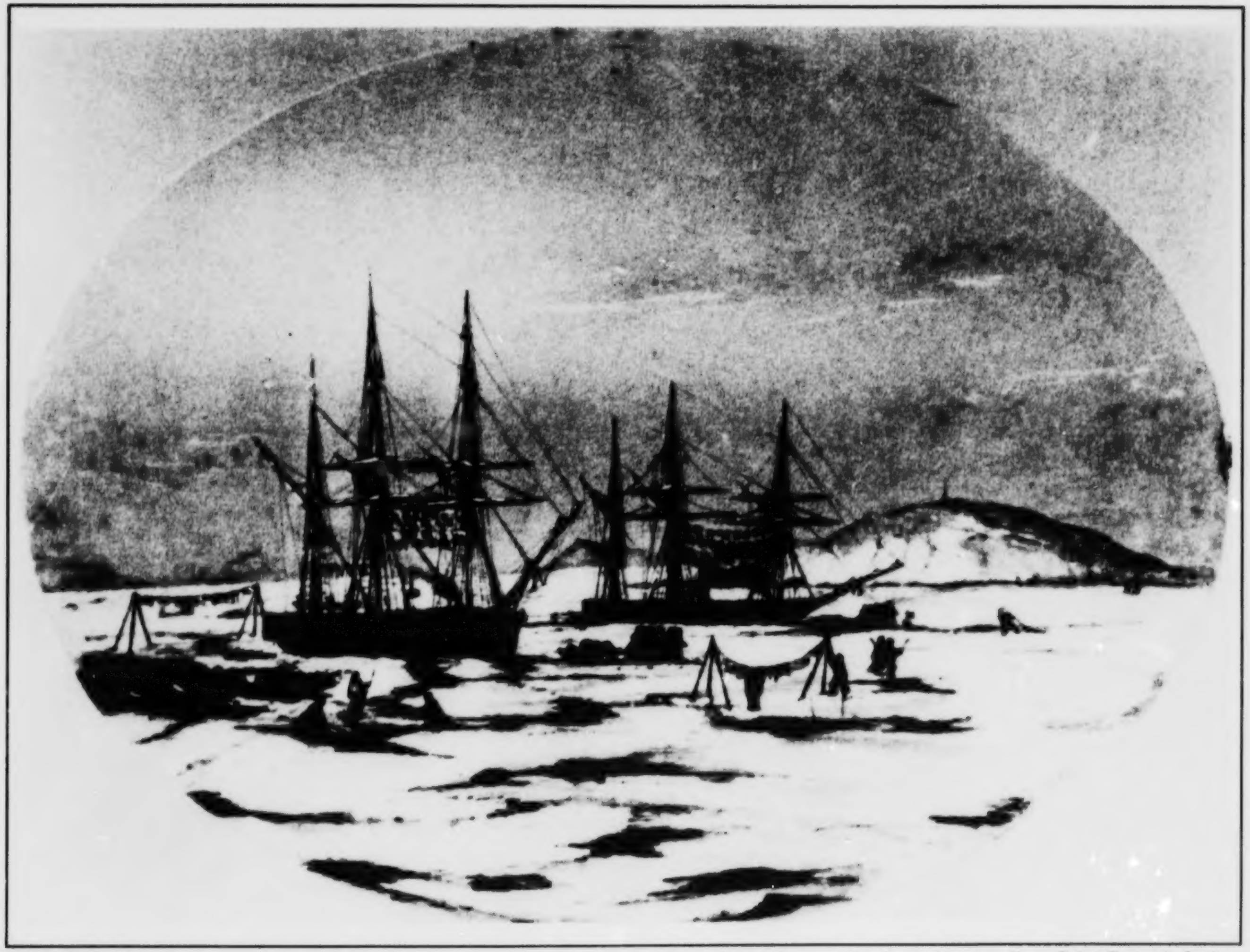


FIGURE 9: De Bray's painting of the ships in spring, showing supplies being sledged ashore to the depot. Courtesy Scott Polar Research Institute.

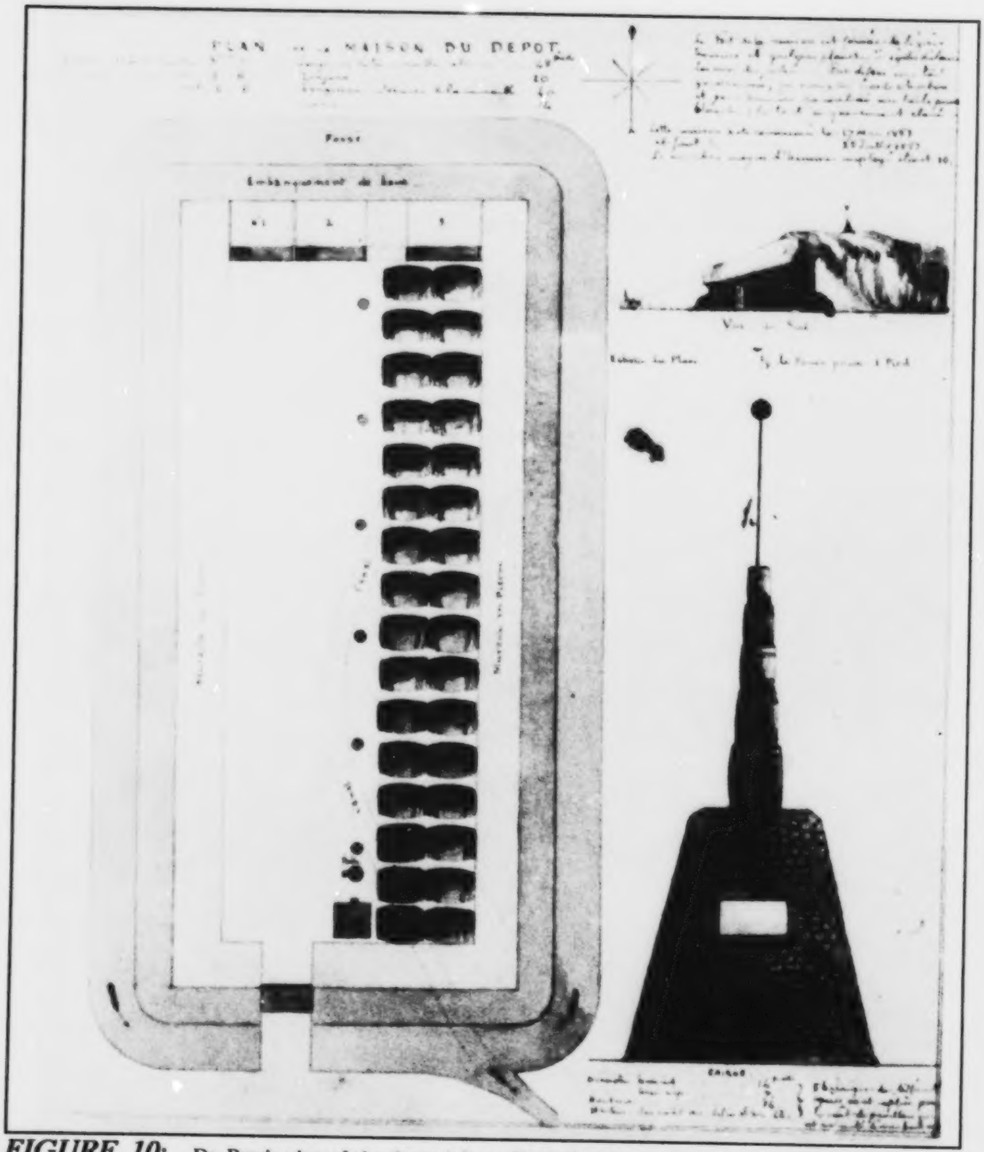

PLAN DE LA MAISON DU DEPOT
Fossé
Embanquement de ...
Vue du Sud

FIGURE 10: De Bray's plan of the depot left on Dealy Island. Courtesy Archives de France.

some progress eastward toward Byam Martin Island. Every opportunity was grasped to hunt muskoxen on Melville Island, and several tonnes of meat were sledged out to the ships.

By the evening of 10 September the ships were solidly beset and drifting east and southeast. Resigning himself to the inevitable, Kellett gave orders to prepare for a second wintering on 20 September. The ships continued to drift southeast, finally becoming immobile at 74° 42'N, 101° 22'W, some 45 km to the southwest of Cape Cockburn on Bathurst Island (Figure 2). The routine was much the same as that of the previous winter with lectures and theatrical performances to help maintain morale. Three deaths occurred during the winter, the bodies in each case being buried through holes cut in the ice.

An interesting innovation, set up by Lieutenant Hamilton and De Bray, was an electric telegraph system rigged between the two ships, which lay about 400 m apart, messages being passed by means of a Morse key. It proved its worth during dinner on New Year's Eve when Thomas Hartnell, one of a trio of musicians on his way from *Intrepid* to *Resolute*, was lost in a blizzard. By using the telegraph it was easy to establish that he had turned back and was safely aboard his own ship.

In the spring there was considerable sledge traffic between *Resolute* and *Intrepid*, *North Star* at Beechey Island, and *Pioneer* and *Assistance*, also wintering for a second time, at Disaster Bay, about 100 km north of Beechey Island. Alarmed at the possibility of yet a third wintering if the ships failed to get free during the summer of 1854, Sir Edward Belcher sent orders to Captain Kellett to make preparations for abandoning both ships. *Resolute's* carpenter began building two new sledges, and an ice-boat was made ready to be cached at Cape Cockburn on Bathurst Island. De Bray was given the task of sledging this boat ashore: he left the ship with a party of nine men and 10 days' provisions on the afternoon of 20 April. Rough pressure-ice made this a slow tedious trip. De Bray and his men often had to unload the sledge and manhandle the boat over hummocks and ridges. It was not until 28 April that they completed their mission and returned to the ship.

On the same day Captain McClintock returned from a visit to *Assistance*, relaying to his officers and men Sir Edward's categorical orders that both ships were to be abandoned as soon as possible. De Bray's views on these orders almost certainly reflect the general feeling aboard the two ships:

> "We still had enough provisions and supplies for another year; we were all in perfect health and filled with great anticipation in thinking of our planned spring journey, which would have led to us finding traces of, or even meeting, Captain Collinson. It might even have led to something akin to Captain McClintock's voyage of 1858 when he found the relics of Sir John Franklin on Prince [sic] William Land." (De Bray n.d., p. 224)

Preparations were made for abandoning the ships. On 4 May De Bray was ordered to prepare to leave for Beechey Island with two sledges, nine dogs and nine sick men; he would be accompanied by Dr. Domville. One man, Thomas Morgan, was extremely ill with scurvy, covered with sores and unable to walk. A hanging cot was rigged for him on one of the sledges. The party set off on 8 May. On the first lap to Cape Cockburn they made poor progress due to the rough ice. On the 14th Dr. Domville decided that in view of the deterioration in Morgan's health he should push on ahead with the invalid in forced marches. Following at a more leisurely pace, De Bray and his party reached *North Star* at Beechey Island on the morning of 25 May; the party of invalids had covered 280 km in 18 days. De Bray was saddened to hear that Morgan had died soon after reaching Beechey Island and had been buried beside the graves of the three members of Franklin's expedition.

By now traffic between *North Star* at Beechey Island and *Assistance* and *Pioneer* at Disaster Bay was so frequent that a series of four staging camps was set up between the two points. On 12 June De Bray was sent north with an urgent message for Sir Edward; travelling with a team of 10 dogs, the 100-km trip look only 20 hours. By the 15th De Bray was back at Beechey Island.

The first leads in the ice of Erebus and Terror Bay appeared on 7 August, and by the 21st *North Star* was floating freely in open water. Since there was little prospect of *Assistance* and *Pioneer* fighting free of the ice, Sir Edward decided to abandon them. Their crews travelled south to Beechey Island partly by boat, partly by hiking overland. It was intended that the entire crews of *Resolute*, *Intrepid*, *Assistance* and *Pioneer*, plus part of the crew of *Investigator* would be transported home aboard *North Star*. This would have meant a total complement of 263 men and would have meant unbearable overcrowding.

Fortunately this did not become necessary. On 27 August the resupply ships *Phoenix* and *Talbot* arrived, and some of the officers and men aboard *North Star* were assigned to these vessels. De Bray found himself aboard *Phoenix*.

A memorial tablet to commemorate Lieutenant de vaisseau Joseph-René Bellot, De Bray's compatriot, who had been drowned when blown off a floe in Wellington Channel in August 1853, had arrived aboard *Phoenix*. It was now erected on the monument which had earlier been raised to the memory of Franklin and his men. The ceremony was attended by most of the officers of Sir Edward's squadron along with those of *Phoenix* and *Talbot*. Very fittingly De Bray was invited to unveil the tablet.

The three ships were homeward bound on 28 August. After calling at Lievely on Disko Ø, *Phoenix* dropped anchor at Cork on 28 September. From there Sir Edward, Captain Kellett and Captain M'Clure left immediately for London to face courts martial, standard procedure when Navy ships had been abandoned. De Bray stayed aboard *Phoenix*, reaching London on 2 October 1854 and Paris soon afterwards.

His contribution had been warmly appreciated by the officers and men with whom he had served. On 30 September Sir Edward wrote to the Secretary of the Admiralty "... to speak in the highest terms of praise of the conduct of M. Emile de Bray". Belcher's letter was forwarded to the French Minister of Foreign Affairs, who in turn passed it to Ducos, the Minister of Marine. Ducos wrote De Bray a letter of sincere congratulations on 13 October. He also sent a copy of Belcher's letter to the newspaper *Moniteur Universel*, where it appeared in translation on 12 October.

Thereafter, honours came in rapid succession. Almost immediately De Bray was named Chevalier de la Légion d'Honneur, and on 29 October was received in private audience by the Emperor Napoléon III (Rouch 1944, p. 7). On 5 October 1855 De Bray was promoted Lieutenant de vaisseau, at the age of 26. By then he was serving as first officer aboard the gunboat *La Poudre* on active service in the Baltic. In July 1857 he was awarded the Arctic Medal by Queen Victoria; in the covering letter the Lords of the Admiralty asked that Admiral Hamelin "... convey to M. de Bray the expression of their utter appreciation of this valuable exertion" (Stewart 1857). The Arctic Medal was simultaneously awarded posthumously to Bellot, but De Bray was the only living Frenchman ever to receive this award. On a more personal level, Lady Franklin sent him a framed portrait of her husband with the dedication "En reconnaissant et affectueux souvenir de ses très habiles et zelés services dans la recherche de mon bien aimé mari" (De Bray, G. 1926, p. 4).

De Bray's subsequent naval career was varied. It included three years in command of a fisheries-protection vessel based at Saint Pierre and Miquelon (1858-1861). During the Franco-Prussian War, while in charge of a brigade of the Third Army of Paris, he found himself commanding a battery at St. Quentin during the defence of Paris in December 1870 (Rouch 1938, 1944, 1945). In recognition of these services he was made "Officier de l'Ordre National de la Légion d'Honneur".

De Bray's health had been badly undermined, in part by his arctic experiences, in part by his three years of service based at Saint Pierre and Miquelon. Illness forced him to take early retirement on 7 October 1878 and he died prematurely in 1879 at the age of 50.

The nick-name given to De Bray throughout his later career was "De Bray Pôle Nord" (Rouch 1938). But there were also two more substantive sequels to his arctic experiences. He was friendly with the novelist Jules Verne, who relied heavily on De Bray for technical details while writing his two-part novel on the adventures of Capitaine Hatteras in the Arctic (Verne 1866A,B). On a different level, in the mid-1860s De Bray was approached by Gustave Lambert (1866, 1868), who offered him command of the vessel *Boréal* on his anticipated attempt at the Pole via Bering Strait. De Bray declined but did offer advice and assistance regarding organization. These plans at a polar attempt evaporated with Lambert's death during the Franco-Prussian War.

De Bray's contribution to the search for Franklin, and hence to the exploration of the Canadian Arctic, was significant. His two long sledge trips from Dealy Island, the one to Cape Providence in the fall of 1852 and the one to Cape de Bray in support of McClintock in the spring of 1853, compare favourably with any of those of his British fellow-officers. The chart that he produced during the second of these trips is an excellent piece of work. Furthermore his supplementary sledge journeys, such as the one with the party of invalids from Cape Cockburn to Beechey Island in May 1854, or his dash north by dogteam with urgent dispatches for Sir Edward Belcher later that month, are not only impressive, but demonstrate the trust placed in him by Captain Kellett.

It is noteworthy that in his journal De Bray frequently includes detail which is rarely, if ever, to be found in those of English officers. For example he provides a detailed description of the pitching and arrangement of the tents used during the sledge journeys, even to such charming details as "When all the men are in their bags one spreads a canvas or very light blanket over them, a little larger than the tent ..." (De Bray n.d., p. 114). Elsewhere he explains how to rig a sail on a sledge.

Not the least of De Bray's contributions is in the artistic realm. The two paintings, of which photographs have survived, show that he combined an eye for detail with true artistic talent. These two works of the wintering ships by moonlight in the depths of winter, then by daylight in the spring, are important additions to the rather specialized genre of mid-Victorian arctic expedition paintings.

Of all the letters of commendation on the character of Enseigne de vaisseau Emile Frédéric de Bray that have survived in the Archives de France in Paris, perhaps the most telling was written by Captain Kellett prior to leaving *Phoenix* at Cork on 28 September 1854:

> "My dear De Bray:
>
> I have already expressed to Sir Edward Belcher commanding the Arctic Expedition my opinion of your conduct whilst serving in Her Britannic Majesty's Ship "Resolute" under my command. But I cannot allow you to leave me without expressing to you personally my admiration of your promptness and zeal in undertaking any piece of service and your ability in its execution.
>
> You have Mr. De Bray done credit to the distinguished service to which you belong.
>
> Thrown amongst us a perfect stranger not even speaking our language with ease, you have so perfectly identified yourself with everything common to us, our duties, amusements and teaching as to have won the esteem and regard of all on board and of none more than of yours
>
> Very sincerely,
>
> Henry Kellett, Captain"
>
> (Kellett 1854)

One would hope that, by this time, Lieutenant George S. Nares would have readily admitted that the "Frenchman" had indeed improved on acquaintance. Cape De Bray on the northwest coast of Melville Island is a fitting memorial to a fine man.

ACKNOWLEDGEMENTS

I thank the staff of the Scott Polar Research Institute for the warm welcome and kind assistance extended to me as a visiting researcher. I am especially indebted to M. Phillipe Henrat of the Archives de France in Paris for supplying me with the photograph of De Bray and of his plan of the Dealy Island store-house. My thanks are also due to Mr. Keith Bigelow of the Department of Geography, University of Saskatchewan, for drafting the maps.

REFERENCES

Bellot, J.-R. 1854. Journal d'un voyage aux mers polaires executé à la recherche de Sir John Franklin en 1851 et 1852. Perrotin, Paris. 415 pp.

______. 1855. Memoirs of Lieutenant Joseph Rene Bellot ... with his journal of a voyage in the polar seas, in search of Sir John Franklin. Hurst and Blackett, London. 392 pp.

De Bray, E.F. n.d. Journal de bord de l'Enseigne de vaisseau Emile Frédéric de Bray à bord de la frégate anglaise "La Résolue". Expédition polaire de 1852-1853 [sic] envoyée à la recherche de Sir John Franklin. Scott Polar Research Institute, MS 864/1. 288 pp. (Typescript).

De Bray, G. n.d. Emile de Bray. Scott Polar Institute, MS 864/3. 4 pp. (Typescript).

Janes, R.R. 1982. The preservation and ethnohistory of a frozen historic site in the Canadian Arctic. Arctic 35(3):358-385.

Kane, E.K. 1854. The U.S. Grinnell Expedition in search of Sir John Franklin: a personal narrative. Sampson Low, Son and Co., London. 552 pp.

Kellett, H. 1854. Letter to Emile de Bray, 28 September 1854. Scott Polar Research Institute, MS 887.

Kennedy, W. 1853. A short narrative of the second voyage of the *Prince Albert* in search of Sir John Franklin. W.H.Dalton, London. 202 pp.

Lambert, G. 1866. Projet de voyage au Pôle Nord. Société de Géographie, Paris. 15 pp.

______. 1868. L'expédition au Pôle Nord. Société de Géographie, Paris. 25 pp.

McDougall, G.F. 1857. The eventful voyage of H.M. discovery ship *Resolute* to the Arctic regions in search of Sir John Franklin and the missing crews of H.M. discovery ships *Erebus* and *Terror*, 1852, 1853, 1854. Longman, Brown, Green, Longmans and Roberts, London. 530 pp.

Nares, G.S. 1852. Letter to W.H. Nares, 15 April 1852. Scott Polar Research Institute, MS 876 1/6.

Neatby, L.H. (Editor). 1967. Frozen ships. The Arctic diary of Johann Miertsching, 1850-1854. Macmillan Co. of Canada, Toronto. 254 pp.

Osborn, S. 1852. Stray leaves from an Arctic journal; or, eighteen months in the polar regions, in search of Sir John Franklin's expedition, in the years 1850-51. Longman, Brown, Green and Longmans, London. 320 pp.

Rouch, J. 1938. Émile de Bray. La Géographie 59(5-6):257-263.

______. 1944. Le journal inédit d'Émile de Bray, explorateur polaire français. Bulletin de la Section de Géographie du Comité des Travaux Historiques et Scientifiques (Paris) 59:1-9.

______. 1945. Deux officiers de marine français, Joseph Bellot et Émile de Bray à bord de navires de S.M. Britannique dans les mers polaires (1852-1854). France - Grande Bretagne 194:1-12.

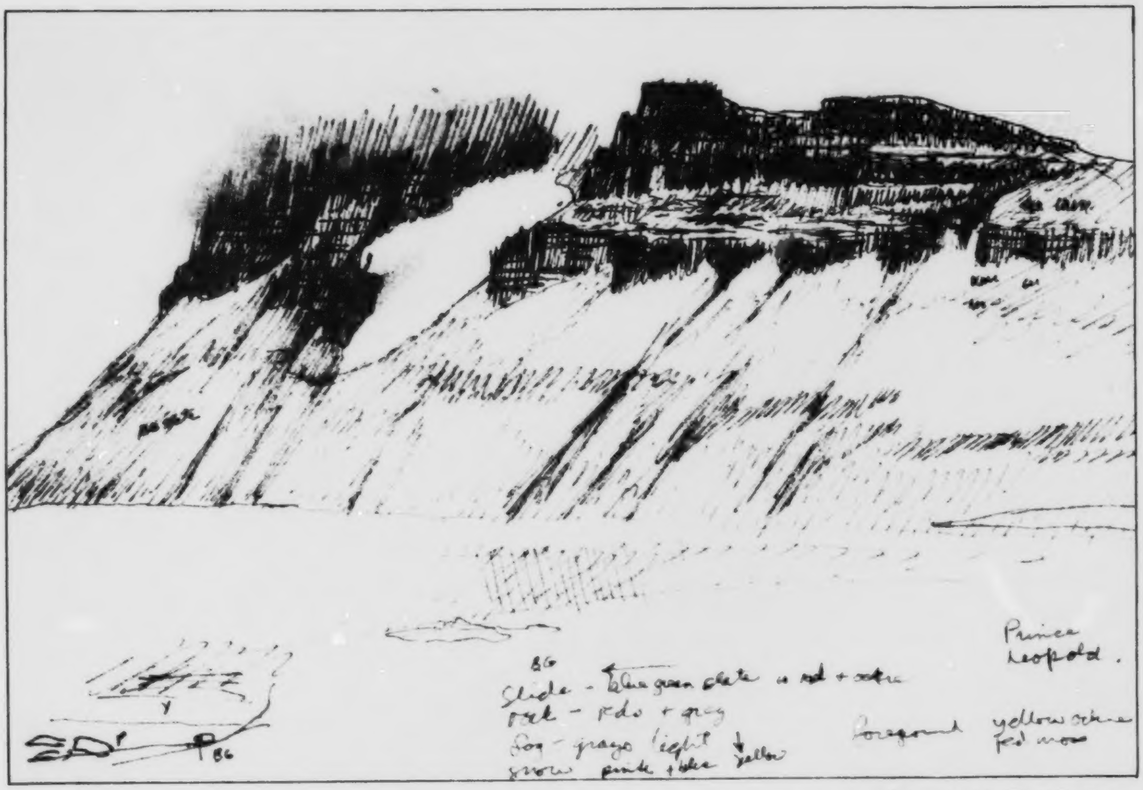
Snow, W.P. 1851. Voyage of the *Prince Albert* in search of Sir John Franklin: a narrative of every-day life in the Arctic seas. Longman, Brown, Green and Longmans, London. 416 pp.

Stewart D. 1857. Letter to Count Walewski, 25 July 1857. Scott Polar Research Institute, MS 887.

Sutherland, P.C. 1852. Journal of a voyage in Baffin's Bay and Barrow Straits in the years 1850-1851, performed by H.M. Ships *Lady Franklin* and *Sophia* under the command of Mr. William Penny, in search of the missing crews of H.M. Ships *Erebus* and *Terror*. Longman, Brown, Green and Longmans, London. 410 pp.

Verne, J. 1866A. Les Anglais au pôle Nord; aventures du capitaine Hatteras. J. Hetzel, Paris. 338 pp.

______. 1866B. Le désert de glace; aventures du capitaine Hatteras. J. Hetzel, Paris. 320 pp.


Prince
Leopold.
BG
Slide - blue green slate w red + ochre
rock - reds + grey
Fog - grays light
snow pink + blue
yellow
Foreground yellow ochre
red moss
Y
BG

Illustrated by Brenda Carter

THE 1983 ELLESMERE ISLAND ARCTIC EXPEDITION

Tim O. Rockwell[1]

Abstract: On 30 June 1983, the United States,Canadian, National Geographic Society and Explorers Club flags were flown on the north shore of Pim Island, Northwest Territories,during a memorial service to commemorate the 100th anniversary of the First International Polar Year. The ceremony was conducted at a point nearly equidistant from Greely's "Camp Clay" (1883-1884), Sverdrup's Fram Haven (1898), and Peary's Payer Harbour Base (1902). The flags were borne by a nine-person expedition composed of students and faculty of the Mercersburg Academy and a representative of the Explorers Club on a 30 km, five-day hike along the rugged coastline of the Johan Peninsula and a 6 km-trek across the deteriorating ice of Rutherford Bay.

The expedition was conceived and directed by the author (Dean of Students at the Mercersburg Academy, a coeducational independent secondary school in south-central Pennsylvania) as a living tribute to Ross. G. Marvin, former faculty member, who died during Peary's 1908 bid for the Pole.

Résumé: Le 30 juin 1983, les drapeaux des États-Unis, du Canada, de la "National Geographic Society" et du "Explorers Club" ont été hissés sur la rive nord de l'île Pim, dans les territoires du Nord-Ouest, lors de la cérémonie commémorative du 100^e anniversaire de la première Année polaire internationale. La cérémonie a eu lieu à un point quasi équidistant du "Camp Clay" de Greely (1883-1884), du "Fram Haven" de Sverdrup (1898) et du "Payer Harbour Base" de Peary (1902). Les drapeaux ont été portés par une expédition de neuf personnes composée d'étudiants et de membres du corps enseignant de la "Mercersburg Academy", ainsi que d'un représentant du "Explorers Club", sur une distance de 30 km lors d'une expédition à pied de cinq jours, le long du littoral accidenté de la péninsule du Johan, suivie d'une étape de 6 km sur les glaces en décomposition de la baie Rutherford.

L'expédition a été conçue et dirigé par l'auteur (Doyen des étudiants à la "Mercersburg Academy", école secondaire mixte indépendante du centre-sud de la Pennsylvanie) en hommage vivant à Ross G. Marvin, ancien membre du corps enseignant, qui mourut lors de la tentative de Peary pour atteindre le Pôle Nord en 1908.

INTRODUCTION

A small expedition composed of students and faculty of the Mercersburg Academy, a secondary independent coeducational boarding school in south-central Pennsylvania, visited the Pim Island-Cape Sabine area of Ellesmere Island during a three-week period in late June and early July, 1983. The purpose was to commemorate the 100th anniversary of the Greely Expedition (Greely 1888); the First International Polar Year, 1882-1883 (Barr 1985); and Ross G. Marvin, Mercersburg Academy faculty member (1907) who died on the Peary North Pole Expedition (Peary 1910). The expedition's primary goals were: (1) to pay tribute to those who opened the arctic frontier; and (2) to kindle at the secondary high-school level an interest in, and knowledge of, the polar regions. Secondary goals were: (1) to replicate Sergeant Long's 1882 trek on the Johan Peninsula (Greely 1886); (2) to conduct field observations and study on flora and fauna - study sessions on these subjects during the preceding school year provided a valuable background for this field work; and (3) to record personal impressions of the arctic environment through diaries and photographs.

---

[1] Mercersburg Academy, Mercersburg, Pennsylvania 17236, U.S.A.

In keeping with the memorial and academic nature of the expedition, contributions to fund the project were solicited from private sources and appropriate scientific or cultural agencies.

The Mercersburg Academy Robert R. Black Alumni Fund for Faculty Summer Study provided faculty stipends. Expedition members were responsible for contributing $1,500 (U.S.) each to meet airfare and personal equipment costs. The National Geographic Society provided a small contingency grant and its official flag. The Explorers Club supplied youth grants for student members and the personal flag of Lowell Thomas, since A.W. Greely had been the Club's first president. The Polar Continental Shelf Project quartered members at Resolute, offered technical advice, reviewed the expedition's plans, and included the expedition in its radio net. The Canadian Embassy in Washington, D.C. supplied maps, general information and a Canadian flag for the ceremony.

Total costs for the nine-person expedition were $23,000 (U.S.) of which $17,000 (U.S.) went to airfare. Transportation involved scheduled commercial flights from Pittsburgh to Resolute via Montreal and Frobisher Bay, as well as a regular schedule flight to Grise Fiord on southern Ellesmere Island. A charter flight to Alexandra Fiord completed this part of the trip. The first attempt to reach Grise Fiord was prevented by heavy ground-fog that delayed the expedition by two days.

In essence, the project demonstrated that a group of highly motivated and properly trained high school students and faculty could plan and accomplish carefully set goals, as well as completing a 10-day 100-km trek in the High Arctic with a minimum of direct support.

As an educational institution at the secondary school level, Mercersburg Academy has had an unusual interest and association with polar affairs. Ross G. Marvin who taught mathematics at the Academy in 1907 (Figure 1) served on Peary's 1905-1906 expedition, and in 1909 perished on Peary's successful 1908-1909 polar expedition (Figure 2). Marvin's death had a lasting impact on the school, since its first Headmaster, Dr. William M. Irvine, held Marvin forth as an example of the school's motto "Integritas, Virilitas, Fidelitas" (Rockwell 1984A).

As early as 1911, Sir Wilfred Grenfell lectured at the school urging and finding support for his humanitarian work in Labrador. His strong relationship with the Academy was further emphasized when a stained glass window depicting Sir Wilfred and the Arctic frontier was included when the Mercersburg Chapel was constructed in 1927, that being a singular

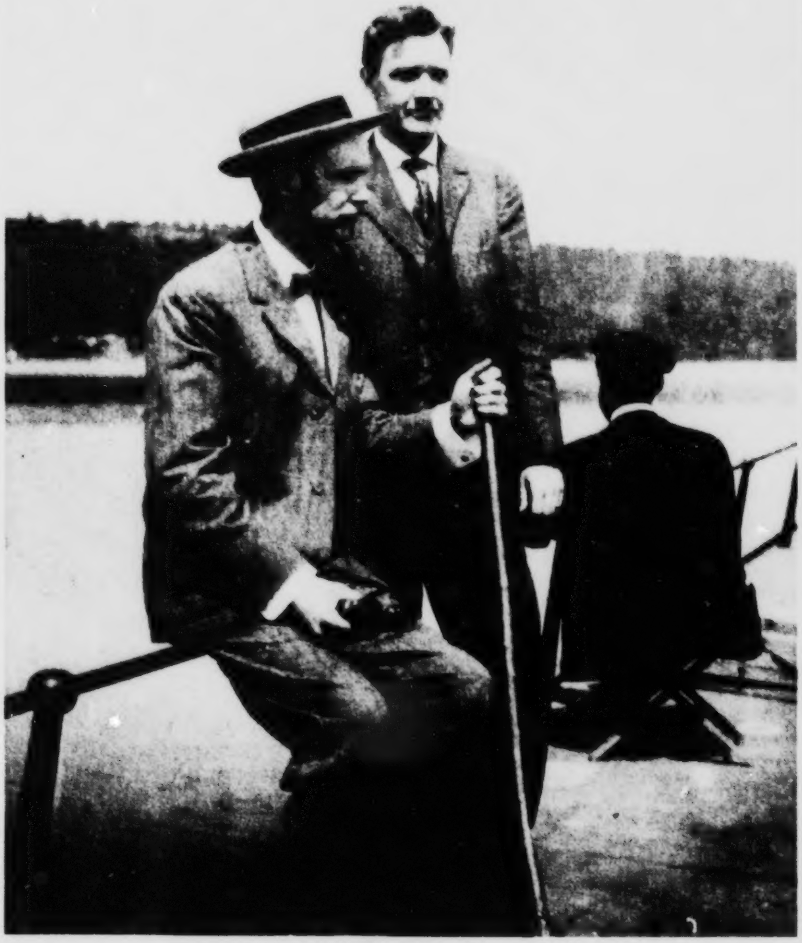


FIGURE 1: **Ross Marvin (seated) in southern surroundings. Courtesy of Chemung County Historical Society.**

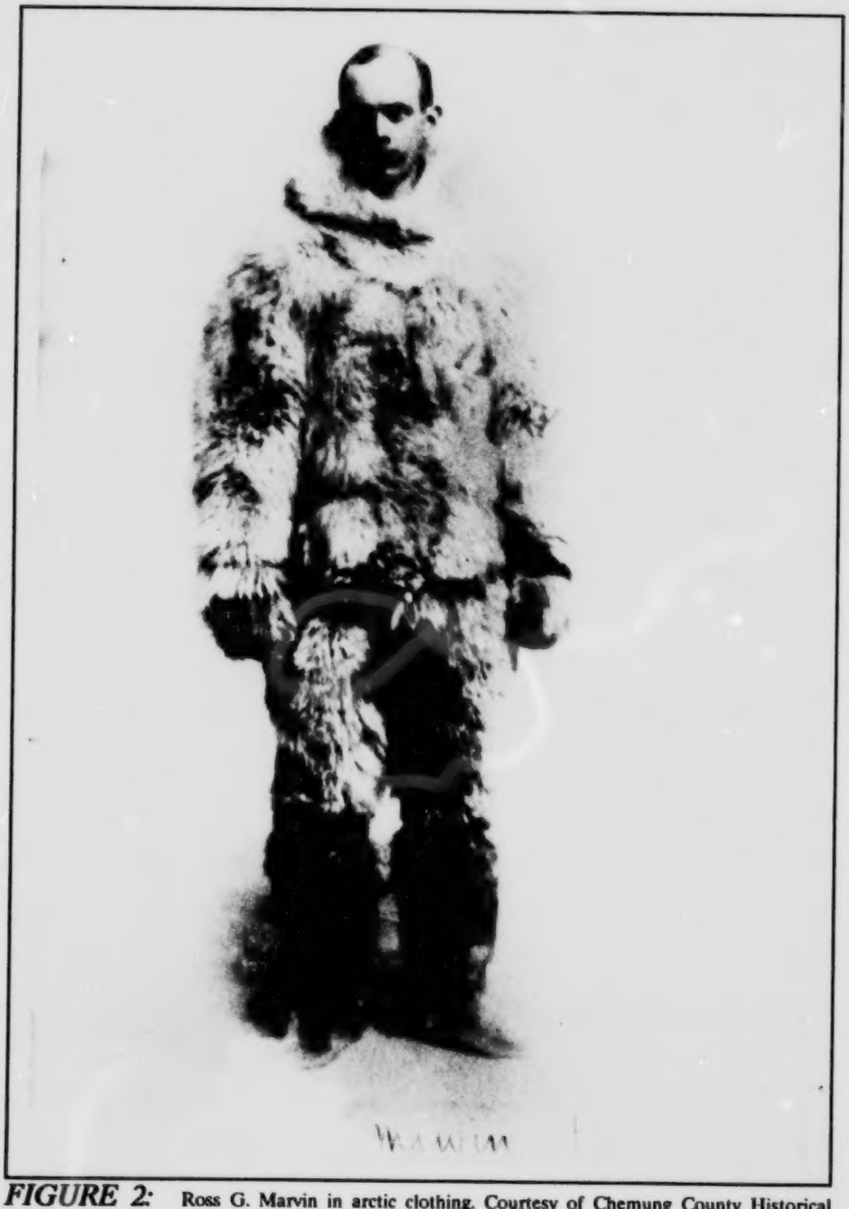


FIGURE 2: Ross G. Marvin in arctic clothing. Courtesy of Chemung County Historical Society.

honor for a living person. Sir Wilfred and Lady Grenfell visited the school for the last time in 1932, shortly before their retirement.

Admiral Peary recounted Marvin's exploits for the student body in 1912, and during the 1930s various lecturers and visitors associated with Byrd's efforts in Antarctica came to the school to share their experiences. Donald MacMillan, who was with Marvin in 1909, rekindled the Arctic interest during the 1950s with various lectures on his past sled trips and then-current sailing ventures in the High Arctic. Commander Calvert, captain of the USS *Skate*, first submarine to surface at the North Pole, lectured Mercersburg students in 1962 (Rockwell 1984B). Thus, the conception, organization, and execution of the 1983 expedition on the 100th anniversary of the First International Polar Year seemed a natural culmination of the school's polar interests, and an apt way to demonstrate its willingness to provide practical arctic field experience for youthful students in history and the natural sciences.

THE DESTINATION OF THE EXPEDITION

Logistics and history dictated the selection of Pim Island and Cape Sabine as the expedition's final destination and the site for its planned commemorative ceremony. Approximately midway between the Arctic Circle and the North Pole, Cape Sabine is the easternmost tip of tiny (6 km x 15 km) Pim Island which lies off the Johan Peninsula on the east coast of Ellesmere Island. With the peninsula, Pim Island forms the narrowest point of the 48 km-wide Smith Sound separating Ellesmere Island from Greenland. Until the time of the Greely Expedition, (Figures 3,4) Cape Sabine was thought to be the eastern point of the Johan Peninsula; however, Sergeant Rice (photographer on the Greely Expedition), during a reconnaissance from Wade Point in 1883, discovered that the area was really a small island separated from the mainland by a narrow strait which now bears his name (Greely 1886).

Lying at the edge of the North Water polynya, the cape's accessibility by water is not always certain. June to July land temperatures near the cape vary from -8° to 5°C.

Because the scientific base at Alexandra Fiord is accessible by Twin-Otter aircraft, it made a perfect staging area from which the novice team of students and faculty could reach Pim Island and Cape Sabine by hiking along the Johan Peninsula.

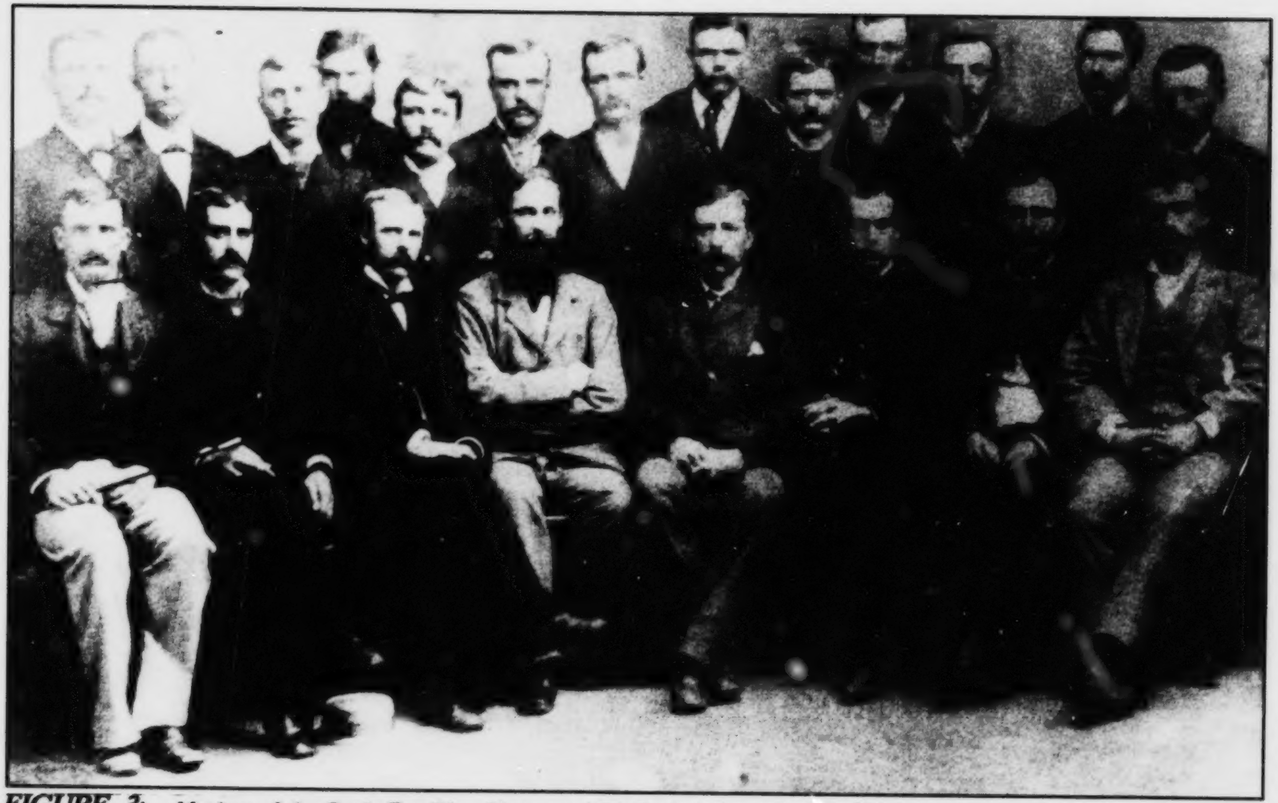


FIGURE 3: Members of the Greely Expedition. Lieutenant A.W. Greely is fourth from the left in the front row.

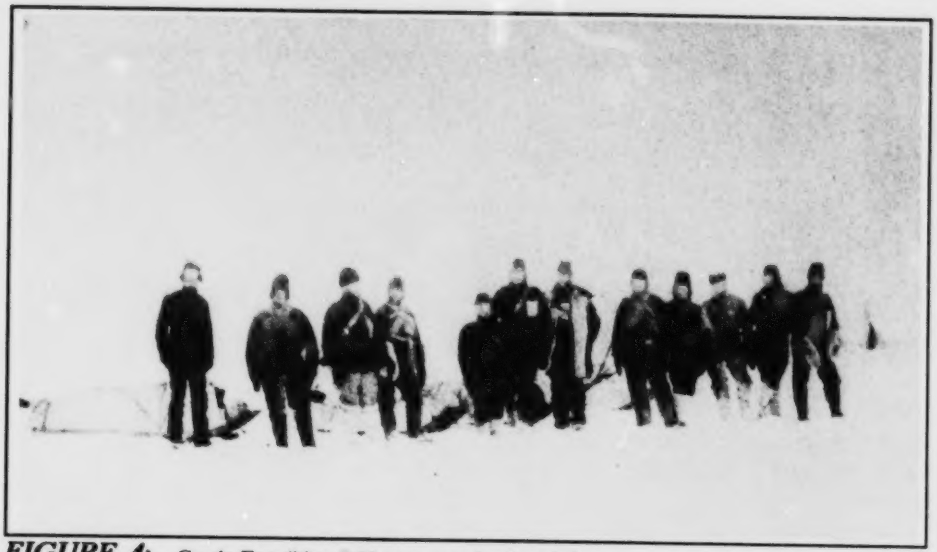


FIGURE 4: Greely Expedition field party man-hauling sledges.

Most significant for the commemorative aspects of the expedition was the varied history and prehistory of Pim Island and its approaches. Recent archaeological investigations on the nearby Knud Peninsula and Skraeling Island indicated prehistoric Eskimo activity and possible Norse contact by 1300 AD (Schledermann 1980). As is well known, Greely retreated to Cape Sabine in 1882 from his more northern station at Lady Franklin Bay after two years of important scientific observations, collection, experimentation and discovery. Unfortunately, 19 of the 25 man party perished at "Camp Clay" on the north shore of Pim Island awaiting rescue, which finally arrived too late in 1883 (Greely 1888; Figure 5). Otto Sverdrup in 1898-1899 wintered near the northern entrance to Rice Strait at Fram Haven and discovered the ruins of Eskimopolis on the Johan Peninsula midway between Alexandra Fiord and Pim Island (Sverdrup 1904). Peary in 1898-1902 used Payer Harbour on the south shore of the island as a support camp for his more northern base at Greely's abandoned Fort Conger on Lady Franklin Bay. Donald MacMillan, former assistant of Peary, made one of the first maps of the area in 1961, and during the winter of 1924 crossed from Greenland to erect a National Geographic Society bronze tablet to the memory of the Greely Expedition at "Camp Clay" (MacMillan, M. 1951). Lieutenant Commander Byrd, flying over that spot with MacMillan in 1925 during one of the pioneering trials of aircraft by the United States in the Arctic, commented that he had "never seen a bleaker spot" (MacMillan, D.B. 1925). In the late 1940s MacMillan again made several attempts to reach the island and "Camp

FIGURE 5: Survivors (all seated) of the Greely Expedition following their rescue from "Camp Clay" in 1883. Greely is in the centre of the group.

Clay" by sea, succeeding finally in 1950 (MacMillan, M. 1951). Since that time the area has been visited frequently by field teams now having easier access by helicopter. However, the fact remains that the Pim Island and Cape Sabine area with its rich prehistory and association with several early arctic expeditions makes it a physical and symbolic confluence of man's conquest of the Far North.

STRUCTURE AND GOALS OF THE EXPEDITION

As with any expedition operating in isolated, unfamiliar terrain, individual and group safety was a primary consideration. Since few true emergencies can be completely foreseen, adequate training and field discipline were stressed to decrease the likelihood of serious problems. Thus, a number of conditions were set: (1) the expedition would not be more than 30 km from the usable airstrip at Alexandra Fiord; (2) radio contact with Polar Continental Shelf Project in Resolute was maintained twice daily; and (3) other Canadian research posts and agencies had been advised of our itinerary. Further, the summer season of 24-hour daylight provided less stress in an unfamiliar environment as well as conditions favourable to more rapid assistance, if needed. All first aid equipment and safety gear, except the radio, was distributed among members of the group so that complete loss of essential emergency equipment was unlikely. Although recorded summer weather conditions for the area were no more severe than those of a mild winter in the continental United States, all camping and personal gear was of high quality alpine-type and serviceable well below the recorded minimums.

Because the expedition was composed of high school students and faculty inexperienced in the Arctic, much consideration was given to selecting a team whose combined physical and psychological strengths and past experience were likely to make the expedition a success. The four faculty members, besides expertise in archaeology, history, mathematics, chemistry and biology, had field experience in hunting, trapping, mountaineering, and extended trekking in the more southerly parts of Canada. The three 17-year old male students and one 20-year old female alumnus were chosen for their keen interest, high motivation, psychological stability under stress, and demonstrated ability to work as a team. As the Explorers Club wished to honour its first president A.W. Greely, the Club secretary, an experienced arctic mountaineer, rounded out the nine-member expedition (Bruno 1984). All participants had to present a reasonable health record and undergo a physical and dental screening prior to departure. Also all members were trained in CPR and basic first-aid, one faculty member being a certified Emergency Medical Technician.

In brief, the expedition met its several educational and commemorative goals. All along Johan Peninsula the group encountered signs of prehistoric Dorset and Thule cultures from tent-rings to half-buried communal buildings. When time permitted, sketches, photos and notes were taken, such as at Eskimopolis. Extreme care was exercised neither to remove nor to disturb any of the remains. Slides and notes on unusual features, such as two large polar bear traps (Schledermann 1978), were later forwarded to the Arctic Institute of North America. Altogether, these on-site visits had a profound impact on the group's appreciation for the cultures and people of the High Arctic.

Signs of historic activity ranged from inland tower cairns on Cape Rutherford to indications on Pim Island of a "butcher station" mentioned in Sverdrup's account of his stay in Fram Haven (Sverdrup 1904). Unfortunately, refuse, such as soda cans and plywood, was found icebound in several spots well down the peninsula from Alexandra Fiord. These, too, provided important, albeit negative, lessons for the group.

After five days of hiking from Alexandra Fiord, the expedition had to cross to Pim Island on a 2 km-wide ice bridge across Rutherford Bay near Cocked Hat Island. Originally, planning had called for a crossing at the narrower Rice Strait, but early break-up necessitated a detour and shortened the time the group had on Pim Island, since a safe return to the peninsula relied on the stability of the ice bridge. These crossing conditions, large tidal cracks, and deteriorating weather hindered the search for "Camp Clay". Reluctantly, but to insure a safe return, we decided to abandon the search and hold the commemorative service where the 1983 expedition first set foot on Pim Island - a point nearly equidistant from Payer Harbour, Fram Haven, and "Camp Clay".

COMMEMORATIVE CEREMONY AND RESULTS OF THE EXPEDITION

With the Canadian, United States, National Geographic Society, Explorers Club flags and a Mercersburg Academy banner flying, the service was conducted abut noon on 30 June

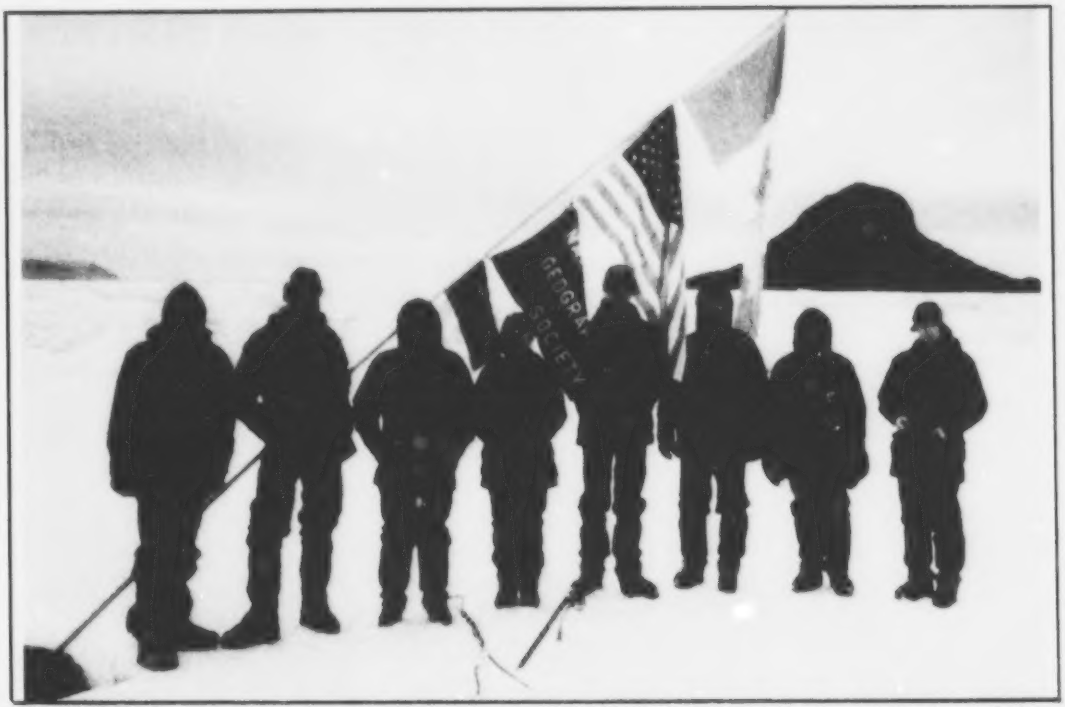


FIGURE 6: Members of the 1983 Ellesmere Island Arctic Expedition on the north shore of Pim Island. Left to right: Tim Rockwell, Frank Rutherford, Jeff Dailey, Shawn Rockwell, Robin Sarner, Brent Gift, Dan Kunkle and Kurt Nielsen. Photo by Shawn Rockwell.

1983 (Figure 6). A prayer was offered for the dead of the Greely Expedition and for "all who, through their lives, extended mankind's knowledge of the polar regions". A small cairn now encloses a brass plaque stating the purpose of the expedition and recording the memorial service.

Upon our return to the United States, summary accounts of the expedition were published in various national and international scientific, professional and educational journals. Student and faculty members gave various slide presentations and lectures to groups of all ages, reaching nearly 5,000 people. Fossils, faunal remains and Inuit art were deposited in the science department's teaching museum. Plant specimens collected by Sergeant Ralston of the 1883 Greely Expedition, and now in the plant collection of the Pennsylvania Department of Agriculture, were brought to Mercersburg for comparison with those collected 100 years later. Other than personal gear, all expedition equipment was donated to the school's outdoor program, and finds continued use. Thus, the 1983 Ellesmere Island Arctic Expedition demonstrated that High Arctic field experiences by qualified, motivated high-school students and faculty are possible and provide unusual long-term learning experiences well worth the effort and planning needed for their safe success.

ACKNOWLEDGEMENTS

I thank the United States Military Historical Institute, Carlisle War College, for permission to use the Greely photographs, and the Chemung County Historical Society for the pictures of Ross Marvin.

REFERENCES

Barr, W. 1985. The expeditions of the First International Polar Year, 1882-83. Arctic Institute of North America, Technical Paper No. 29.

Bruno, J.C.D. and T.O. Rockwell. 1984. The Greely Commemorative Expedition. Explorers Journal 62(2):50-53.

Greely, A.W. 1886. Three years of Arctic service: an account of the Lady Franklin Bay Expedition of 1881-1884. Scribner, New York.

______. 1888. Report on the proceedings of the United States Expedition to Lady Franklin Bay, Grinnell Land. Government Printing Office, Washington, D.C.

Peary, R.E. 1920. The North Pole. Stokes, New York.

MacMillan, D.B. 1925. MacMillan Arctic Expedition returns. National Geographic 48:477-518.

MacMillan, M. 1951. Far North with 'Captain Mac'. National Geographic 100:465-513.

Rockwell, T. 1984A. Ross Gilmore Marvin (1880-1909): explorer and teacher. Fram: Journal of Polar Studies 1(2):375-378.

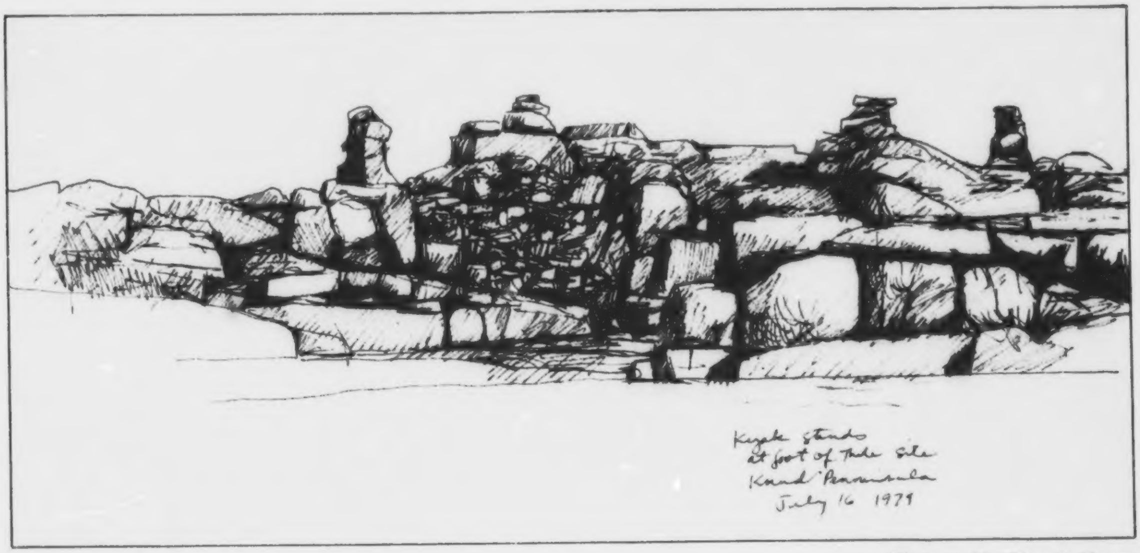
______. 1984B. The 1983 Ellesmere Island Arctic Expedition. Fram: Journal of Polar Studies 1(2):447-460.

Schledermann, P. 1977. Eskimo trappers on Ellesmere Island, N.W.T. Western Canadian Journal of Anthropology 7(1):84-99.

Schledermann, P. 1978. Preliminary results of archaeological investigations in the Bache Peninsula region, Ellesmere Island, N.W.T. Arctic 31(4):459-474.

______. 1980. Notes on Norse finds from the east coast of Ellesmere Island, N.W.T. Arctic 33(3):454-463.

Sverdrup, O. 1904. New land: four years in the Arctic region. Longmans, Green, London. 2 volumes.



Kayak stands
at foot of Thule site
Knud Peninsula
July 16 1979

Illustrated by Brenda Carter

EXPLORATORY MOUNTAINEERING IN THE ARCTIC ISLANDS

G.V.B. Cochran[1]

Abstract: The superb mountain terrain that lines the eastern coasts of the Canadian Arctic Islands is little known outside Canada. In fact, although mapped by aerial photography, the interiors of these mountain ranges still harbour some of the last places on earth that have escaped human visitation. Tourist attention is being drawn to some of these areas by the establishment of National Parks on Baffin and Ellesmere islands, but elsewhere there still are vast areas that are seldom, if ever, visited that could offer a strong attraction to mountaineers around the world.

Since 1967, the author has organized 11 expeditions to explore and climb in virgin areas of these mountains. On Ellesmere Island, these expeditions have visited the mountains of Yelverton Bay and Mackinson Inlet. On Baffin Island, activities have been centred on Bylot Island, Erik Harbour, and two areas of the Cumberland Peninsula: one north of Kingnait Fiord and the other west of Cape Dyer. In addition to mountaineering, glacier studies have been conducted in cooperation with the Glacier Inventory of Canada, and strain-gauge studies, related to the stress analysis of sea ice, have been accomplished with logistical support from Polar Continental Shelf Project.

This paper reviews briefly the history of exploratory mountaineering in the Arctic Islands, comments on expedition logistics, and provides a synopsis of the author's experiences, highlighting the key role played by Inuit in the success of several of these undertakings.

Résumé: Les superbes montagnes qui bordent les côtes et des îles de l'Arctique canadien sont peu connues à l'extérieur du Canada. En fait, bien que cartographié par photographie aérienne, l'intérieur de ces chaînes de montagnes abrite certains des derniers endroits de la planète encore inexplorés par les humains. L'attention des touristes a été attirée sur certains de ces endroits par la création de parcs nationaux sur les îles de Baffin et d'Ellesmere, mais, ailleurs, il y a encore de vastes régions qui ne sont visitées que rarement, voire jamais, et qui pourraient fortement intéresser les alpinistes du monde entier.

Depuis 1967, l'auteur a organisé 11 expéditions d'exploration et d'alpinisme dans les régions vierges de ces montagnes. À Ellesmere, ces expéditions ont parcouru les montagnes de la baie Yelverton et de l'inlet Mackinson. Sur l'île de Baffin, elles ont porté sur l'île Bylot, Erik Harbour, et deux régions de la péninsule de Cumberland: une au nord du fjord Kingnait et l'autre à l'ouest de Cape Dyer. En plus d'y faire de l'alpinisme, on y a effectué des études de glaciers, en collaboration avec l'Inventaire des glaciers du Canada, et des études de tensiométrie, liées à l'analyse de stress de la glace de mer, avec le soutien logistique de l'Étude du plateau continental polaire.

Cette présentation fait un bref historique de l'alpinisme d'exploration dans les îles de l'Arctique, offre quelques commentaires sur la logistique des expéditions, et résume les expériences de l'auteur, soulignant le rôle essentiel des Inuit dans les succès de plusieurs de ces entreprises.

INTRODUCTION

Mountains, glaciers and ice caps are major features of the Arctic Islands. Aside from being of interest from a scientific standpoint, these mountainous areas have another intrinsic attraction: they represent one of the last frontiers for exploratory mountaineering - a discipline that might be described as mountaineering "not because it is there", but because one seeks to know what is there. It is mountaineering where curiosity is at least as important as challenge. Along with Antarctica, Greenland and the Himalayan Kingdom of Bhutan, the Arctic Islands offer a locale where there still are abundant unclimbed summits. Probably there are places where no one has ever been.

---

[1] Orthopaedic Engineering and Research Center, Helen Hayes Hospital, West Haverstraw, New York 19003, U.S.A.

The mountains of the Arctic Islands are part of a chain extending from Labrador up the east coast of Baffin, Devon and Ellesmere islands that continues west across northern Ellesmere Island. Most mountains are of Precambrian rock, but this changes to sedimentary formations as the range extends westward on Ellesmere Island. In general, the peaks range from 2,000-7,000 ft (610-2,130 m), not high as mountains go, but impressive in many locations because they rise from a base near sea level. A few higher summits such as Mount Barbeau (8,540 ft or 2,600 m) in northern Ellesmere Island exist, but they are nunataks that rise from high inland ice plateaus. Perhaps the best known mountains are those of Pangnirtung Pass on Baffin Island, now within Auyuittuq National Park. Here several impressive peaks such as Mount Queen Elizabeth rise to 7,000 ft (2,130 m). While this area attracts hundreds of visitors each year, few expeditions ever attempt to visit the thousands upon thousands of square miles of mountains that exist elsewhere in the Arctic Islands.

HISTORICAL ASPECTS

Development of exploratory mountaineering in the Arctic Islands is best understood in terms of the activities of several individuals, each of whom has organized a number of expeditions. On Baffin Island it began with the expedition led by J.M. Wordie (1935), a veteran of Shackleton's Antarctic expeditions. Arriving by boat, his group discovered the spectacular rock peaks in the region of Sam Ford Fiord, north of Clyde River. Longstaff and Hanham climbed Eglinton Tower, while Ritchie and Baird ascended Pioneer Peak.

Pat Baird, who became the true father of exploratory mountaineering on Baffin Island, thus began his career as a member of Wordie's expedition. After a dogsled exploration across part of Bylot Island (with several first ascents) in 1939, followed by important activities in the Arctic during the Second World War, Baird returned to the Clyde area with the joint Canadian-Swiss expedition in 1950 (Baird 1950). While this was mainly a government-sponsored scientific project based at Sam Ford Fiord, they managed to climb 17 peaks on the side! Later Baird was a prime-mover in the 1953 Arctic Institute Expedition that was based at Pangnirtung Pass and accounted for many first ascents in that area including Mount Asgard (6,598 ft or 2,010 m) (Baird 1953, 1954). Following this he organized two Alpine Club of Canada (ACC) expeditions in the early 1960s that made many more first ascents (Baird 1964, 1966).

Another important expedition to Pangnirtung Pass was made in 1961 by a group from Cambridge University led by R.E. Langford (1962). They completed the first crossing of the peninsula from North Pangnirtung Fiord to Pangnirtung Fiord in summer and achieved seven important new ascents.

In 1962, H.W. Tilman (1964A) sailed his schooner *Mischief* into Totnes Road near the Arctic Circle on Baffin Island. There he landed and climbed Mount Raleigh as well as a neighboring peak he named Mount Mischief. Typical of many of the prominent mountains of the Arctic coast, Mount Raleigh was named not by a mountaineer but by a seafarer (in this case John Davis in 1594). Tilman next sailed *Mischief* to the northern coast of Bylot Island in 1963 and from there made a complete crossing of the island, ending on the Sermilik Glacier opposite Pond Inlet. It was an extremely difficult trip due to deep, soft snow. Although he crossed a 5,700 ft (1,740 m) pass, he did not attempt any summits due to the snow conditions (Tilman 1964B). Two earlier ascents, including Mount Thule, had been made on the south coast of Bylot Island by two Americans in 1954 (Ferris 1955), whereas Baird had made others in the interior of that region in 1939.

Ted Whalley is another individual with a sustained dedication to Arctic mountains. Originally a member of two of the ACC expeditions to Pangnirtung (Baird 1964, 1966), he continued on his own with three major expeditions to the mountains north of Clyde River - an area of alpine terrain that rivals Pangnirtung Pass. In 1973 his expedition was based at Swiss Bay south of Sam Ford Fiord (Whalley 1974), in 1977 in Stewart Valley to the north (O'Connell and Whalley 1978), and in May 1979 among the virgin peaks of Ayr Lake, where they travelled overland by sleds from Clyde River (Whalley 1980). Whalley was co-leader with the author of two Canadian-American Expeditions to Makinson Inlet on Ellesmere Island in the 1970s (Cochran and Whalley 1977; Cochran 1979A).

I began my series of 11 expeditions in 1967 on Baffin Island when the days of the true pioneers drew to a close. As outlined below, these expeditions covered five areas ranging from Cumberland Peninsula to northern Ellesmere Island, and accounted for several dozen first-ascents, and exploration of a score of major glaciers from 1968 to 1987. In addition to the published accounts, complete reports of expeditions were submitted to appropriate agencies of the government of Canada and/or the Northwest Territories.

Laurie Dexter, an Anglican minister who lived for several years in Pond Inlet, is another dedicated exploratory mountaineer. He specialized in climbs along the southern coast of Bylot Island, and later completed an ambitious west-east traverse of Bylot Island on skis, making several first-ascents (Kelly 1978). He also made a number of first-ascents at Grise Fiord including Grise Tower.

Others who have made many trips to the Arctic include John Amatt, a Canadian with a special interest in student expeditions, typified by his 1974 expedition to Kingnait Fiord (Amatt 1975), and Dave McAdam, the famous lone-walker of Baffin. McAdam made a series of solo, summer expeditions through the Cumberland Peninsula and achieved many non-technical first-ascents as recorded frequently in the *Canadian Alpine Journal*. He also noted the lack of interest by outsiders in the more remote regions of Auyuittuq National Park (McAdam 1981). Aside from repeat visitors, a French ski-expedition explored the region southeast of Pond Inlet in the late 1970s, and several British schools sent expeditions to Baffin Island.

Ellesmere Island is extremely mountainous too: the northern part has summits exceeding 8,000 ft (2,440 m). Although many are nunataks, others, including Commonwealth Mountain, present a more alpine face and there are fine opportunities for ski-mountaineering. The first important summit climbed was named Mount Oxford by the Oxford University Ellesmere Land Expedition of 1935 - apparently the only group to visit the ice-cap before the 1950s (Moore 1936). Then after the Second World War, Geoff Hattersley-Smith led many scientific expeditions to northern Ellesmere Island under the auspices of the Defence Research Board (Hattersley-Smith 1974). Bases were established at Lake Hazen and later Tanquary Fiord. Although primarily concerned with science, he and members of his expeditions pioneered exploratory mountaineering on Ellesmere Island. They climbed many summits near Lake Hazen, including Mount Whistler (8,500 ft or 2,590 m)), seen and named by A.W. Greely in 1882. Later they discovered and climbed a slightly higher summit farther west (Mount Barbeau). This 8,540 ft (2,600 m) peak is the highest in North America east of the Rockies (Hattersley-Smith 1962, 1970).

The British armed services also climbed on northern Ellesmere Island. The Royal Air Force Ellesmere Island Expedition, led by Wing Commander Derek Bird, explored the northern mountains in 1967. From a base at Tanquary Fiord, his group crossed to McClintock Inlet and climbed Commonwealth Mountain and Mount Barbeau. Later, the

Royal Navy Ellesmere Island Expedition, led by Commander Angus Erskine, landed by air directly on the ice-cap near the head of Milne Glacier to explore the British Empire Range. After descending that glacier to the sea, they crossed the ice-cap back to Tanquary Fiord using skis and man-drawn sleds, climbing 13 peaks along the way (Erskine 1974). Expedition member Mike Banks probably described best the attraction of climbing north of latitude 80°: "These peaks ... were straight forward snow climbs. The attraction did not lie in their difficulty, but in the deep satisfaction in exploring and climbing lonely and shapely mountains in an exceptionally remote and inaccessible region of the Arctic" (Banks 1974). Not to be outdone, the British Army organized an extensive climbing expedition to the mountains of Axel Heiberg Island (Muston 1974). Also there was a primarily scientific, Joint Services Expedition to Princess Marie Bay on Ellesmere Island in 1980 (Williams 1980).

Steve Trafton and colleagues, mostly from the State of Washington, initiated two extensive ski-mountaineering expeditions across the high ice-plateaus of northern Ellesmere Island: one to the Victoria and Albert Mountains (Goodman 1982), and one to the Mount Barbeau area (Errington 1983). The same group had mounted an expedition to Broad Peak on Sam Ford Fiord, Baffin Island, in 1978 (Errington 1979).

Thus, only a few years ago, it was still possible for expeditions in the Arctic to reach vast, untouched terrain. Now the options are shrinking, and much unexplored mountaineering country has been visited by helicopter-borne mapping and geological parties that have been active since the mid-1970s. Still, large areas of mountains remain unexplored by land-parties and there are hundreds, if not thousands, of virgin summits. Fortunately for exploratory mountaineers, most climbers seek the technical challenges among the peaks of Auyuittuq National Park. While many significant technical climbs from Pangnirtung Pass, such as those of Scott (1973), have been made since the 1960s, these activities are beyond the scope of this paper; details may be found in *The Canadian Alpine Journal*, and *The Alpine Journal*.

EXPEDITION ORGANIZATION AND LOGISTICS

Objectives

The first step in organizing an exploratory mountaineering expedition is to define an objective. Like any research project, finding unclimbed peaks requires knowledge of what is there and what has been done before. Knowledge of what exists stems from maps and aerial photographs, in particular the tri-camera coverage (from 20,000 ft or 6,100 m obtained about 1950) and the vertical coverage obtained from 30,000 ft (9,150 m) in the late 1950s (National Air Photo Library, Ottawa). The latter photographs are the basis for the excellent 1:250,000 maps first produced in the 1960s and 1970s by the Department of Energy Mines and Resources. Using these maps in conjunction with the original aerial photographs provides an excellent planning and navigation tool. Certain editions of the 1:500,000 National Topographic Series with aeronautical information also can be useful for spot altitudes. It is sometimes difficult to explain how one can reach an area where literally no one has ever been, and yet be standing there with an excellent map! Such is the advantage of photogrammetry.

Up to the mid-1960s the best maps of many remote areas of Canada were the older NTS 1:500,000 editions. Many of these included fascinatingly-vague areas marked "relief data incomplete", a sure clue to a possibly virgin area! Today relief data are good, but most features still lack names. Thus a cluster of named features on a map usually indicates that an expedition has been there. To find unclimbed peaks, one must locate a nameless area with map-contours indicating high relief, then research the mountaineering literature.

Organization

Once an objective is selected, the expedition must be organized, equipped and financed. My experience has been with small expeditions of four to 10 men and women. Six is probably the ideal, combining strength for safety with flexibility for simultaneous climbs on different objectives. Whatever the objective, it is important that all members agree on it beforehand. Misunderstandings about expectations for the expedition may cause problems that can be compounded by anxieties developing in the extreme isolation of the Arctic.

Financially, most small expeditions are best supported by dividing costs among the members. Although grants and commercial support are sometimes available, such support is ever more difficult and time-consuming to obtain. Surprisingly, while not cheap, most expeditions can be accomplished for no more than one might spend on a normal vacation. Once in the field, it costs little to remain because the expenses are mainly in air fare, charter costs, air-freight and major equipment such as boats, motors or snowmobiles. Usually such equipment can be sold at cost in the Arctic after a few weeks of expedition use. Firearms are necessary for protection from polar bears. But guns should be carried only in accordance with legal requirements and after consultation with the Royal Canadian Mounted Police. It is most efficient to prepack and send all backpacking food by air-freight. Although adequate food for local use is available in the settlements, an expedition can strain supplies. A week of extra rations is essential in an environment where weather rules transportation.

Communications today are easy using the SBX-11 single side-band radiotelephones made by Spillsbury and Tindall. This set, weighing less than 10 lbs. (4.5 kg) with batteries, usually provides excellent contact over several hundred miles (with a dipole antenna), but sunspot activity and problems due to geographical location can interfere.

Access

Reaching the mountains of the Arctic Islands first became feasible for small private expeditions in the 1960s when commercial flights began regular service to Frobisher Bay (Iqaluit) and Resolute at fares low enough to be competitive with those to mountains elsewhere. Even now it is amazing to think that one can fly to Resolute, within a thousand miles of the North Pole, for less than a full fare from Montreal to Vancouver!

From Iqaluit or Resolute, the next stage involves a flight to an Inuit settlement in a propeller-driven aircraft. Only a few years ago, scheduled service to the settlements was based more on imagination than reality, and flights were cancelled unless an adequate load was available; thus it was far safer to charter. Today, scheduled flights to the settlements along the coast of Baffin Island have greatly improved, although weather is always a critical factor. Also, direct flights from Iqaluit or Resolute to an expedition-base often are possible if suitable landing-site are available.

If an Inuit settlement is selected as the point of departure, the work begins in earnest from there, as the best mountain areas usually are 50-150 miles (80-240 km) distant. The method of reaching the mountains and the mode of travel among them depends on which of two seasonal "windows" has been selected.

The first is the *summer window*. This implies boat travel, but in most areas residual sea ice makes travel uncertain until August. While the water stays open into October, the weather tends to deteriorate in September, leaving August as the best compromise. A few places (e.g. Pangnirtung Pass) that require travel only on the inner reaches of fiords can be reached much earlier. Actually, August in the Arctic marks the beginning of fall with darkness (enough to see the stars, but light enough to climb) returning for a few hours at night. One advantage of August is that mosquitos are fewer.

Boats available range from diesel-driven "Peterhead"-type craft down to the ubiquitous 22-foot freighter canoe driven by a 20 h.p. outboard motor. In earlier years it was usually possible to reach an Inuit settlement and make arrangements for boat travel on the spot. Now with the advent of tourism, this has become more difficult and expensive. Except for visits to a tourist area such as Auyuittuq Park, expeditions today are best advised to bring their own inflatable craft.

Direct flights to a basecamp also are possible in the summer for Twin Otters with balloon tires, but landing-sites in the mountains are scarce, and are usually limited to beaches or flat gravel-beds along rivers. In summer, it is best to know of a landing-strip in advance lest the cost of a charter flight to and from the area be forfeit!

Once landed, whether by boat or air, expeditions must backpack anywhere from 5-20 miles (8-32 km) into the mountains. Probably two full loads per person will be required to support operations with climbing and emergency gear for 10 days or more. While trekking inland, rivers are a serious and dangerous obstacle in summer. Route planning must seek to avoid crossing rivers whenever possible. All but the smallest streams can be uncrossable without special gear, because a heavily-loaded climber who gets above the knees in a fast melt-stream can soon be in trouble. By August the diminution of glacier runoff at night may make early morning crossings easier.

Glacier valleys make the best highways, with the glaciers reaching to anywhere from tidewater to 10 miles (16 km) inland. The terminus usually is guarded by moraines which can make rough going. Once past the moraines, summer glacier travel in the zone of bare ice is easy, although one must be wary of crevasses. In this zone crevasses can be extremely deceptive because they may be covered by a residual and extremely fragile snow bridge that appears only as an innocent-looking band of dirty snow on the bare ice.

Moving up to more permanent snow (usually at an altitude of 1,500-2,500 ft or 460-760 m), a transition zone of glacier morasse or slush may appear. This can be extremely hard on the feet, and there seems to be no good way to deal with it, although modern plastic double boots help. Also it is convenient to carry a pair of wet-suit booties to use as an alternative to the regular inner boot, both for river crossings and morasses. Higher up the snow deepens, and may become impassable, because at each step one sinks unpredictably through successive layers of insubstantial crust. This condition usually does not improve much "at night", and firm snow seldom will be reached at altitudes below 4,000 ft (1,220 m). Thus small, lightweight snowshoes are essential items for summer travel. Substantial new snow also may be encountered in August. Temperatures in the summer window can range from -5° to 15°C.

The *spring window* for Arctic mountaineering is April through May or early June. Here an entirely different environment is encountered - the "spring weather" simulating January in Ottawa. On Ellesmere Island, snow covers much of the land down to sea level into June, and the sea ice is solid almost everywhere into July. Temperatures range from -35° to -15°C in late April and from -20° up to 0°C in May. Daylight lasts for 24 hours, and the sun's rapidly increasing ascension accounts for the rise in temperature leading to a major melt-off in June. On Baffin Island, conditions are similar, but with the season advanced by two weeks or more.

Under "spring" conditions, travel to the mountains from a coastal settlement can be accomplished over the sea ice by snowmobiles pulling komatiks. These Inuit sleds, 10-18 ft (3-5.5 m) long, can carry a load of 1,000 lbs (450 kg) including two riders. Under good snow conditions, overland travel to reach inland glaciers or to cross between fiords also can be accomplished, but with more difficulty. While the idea of dogs is attractive, it is rather impractical for a small, short-term mountaineering expedition to obtain and use dog-teams today.

Conditions during snowmobile sledding can be arduous. While the environment is different, it is difficult to say whether summer travel in an open boat (in a wind with wet snow or rain at temperatures around freezing) is more uncomfortable than riding into the wind on a speeding komatik at dry temperatures of -15°C. In both cases, the rule is put on *all* the clothes available *before* starting.

Komatik travel is a fascinating sport, best learned from Inuit by on-the-job training. For example, it is easy to drive a snowmobile on level sea ice at 20 mph (32 kph) while pulling a half-ton (.45 MT) komatik on a 20-ft (6-m) rope. But one's reflexes must be trained to drive the skidoo to the side when the brakes are applied: there are no brakes on the behemoth closing in from behind! On land, travelling with an overloaded komatik in soft snow can be backbreaking. Each time the skidoo tread "blows" traction, the riders jump off and haul the sledge up close behind the machine. Then the driver takes off at full speed to try a shock start while the riders push, then scramble to jump on before being stranded. Travelling downhill with the loaded komatik cinched up tight to the skidoo (which hopefully acts as the brake) can be terrifying, while travelling over rough sea ice in deep snow in the fog offers the opportunity for backbreaking work and terror simultaneously. The great flexibility of these sleds (held together by lashing) is the key to their superb performance on rough, hard terrain, but also makes securing the load a task of considerable art.

Flights by ski-equipped Twin Otter direct to an expedition base are far more feasible in spring than in summer, because landing sites on sea ice or snow covered glaciers are readily available. The main problem is that it is difficult to determine the weather at a remote site before departure. Even in good weather, local ground-fogs or an overcast sky can abort a landing in a spot where the white conditions make determination of ground-level difficult. Once a party is on the ground, tents or garbage-bag markers make it easier for incoming flights to discern ground-level. On-line satellite photos in Resolute now make it possible to detect cloud-cover over proposed landing-sites, so today this approach is more feasible than a few years ago.

Inland travel is relatively easy in the spring using skis equipped with synthetic "skins" for climbing and pulling fibreglass sleds (Mountainsmith, Boulder, Colorado). In this way, each expedition member can carry 100 lbs (45 kg) or more with ease: up to 40 lbs (18 kg) in a backpack and 60 lbs (27 kg) or more on the sled. This permits operation away from basecamp for two weeks on one load. Mountaineering skis with convertible bindings (such as Ramer or Silvretta) that are usable with plastic, double mountaineering boots are recommended. Insulated overboots or mukluks are useful as backup. While cross-country skis can be used by experts, they are less stable and provide less traction while pulling a sled uphill on difficult and icy terrain.

Other Mountaineering Aspects

On glaciers, at all seasons, extreme caution is required, because even relatively static Arctic glaciers can be heavily-crevassed and snowbridges tend to be fragile. On peaks, climbing routes range from simple walkups or ski ascents on rubbly ridges, to alpine-style ridges, to highly-technical faces, more or less at the option of the climber. Despite the low overall elevation, most climbs cover 2,000-4,000 ft (610-1,220 m) of altitude. Unfortunately, the rock usually is rotten. In the summer, new snow can bring frequent avalanches, and in the spring there can be *extreme* danger from heavy wind slab conditions.

Thus, it is well to remember that on almost any expedition to the Arctic mountains, the group must be entirely self-reliant and exercise utmost care. As the routes are unknown, full alpine gear, including crampons, should always be carried, even for an "easy" day, because many summits are covered by a thin capping of ice. For practical purposes any expedition can be cut off from effective outside aid for many days, and no expedition should get into any situation from which it cannot extricate itself.

Obligations and Rewards

Exploratory mountaineering implies a step beyond simple recreation, because there is an element of learning and an obligation to report one's findings and activities both in the literature and to government agencies. One reward is the fact that the first expedition to an area begins a local history which is extended by each successive foray. The opportunity to name important features in consultation with the Canadian Permanent Committee on Geographic Names is another attraction, as is the opportunity for undertaking even limited scientific observations. For example, I was pleased to be able to cooperate with the Glacier Inventory of Canada on several occasions and to conduct work on strain-measurements in sea ice (Cochran 1980).

Finally, the mountain explorer is a visitor to a land that is exceedingly fragile - one that must be treated with the utmost respect. Even the smallest wound on High Arctic tundra can take years to heal. The interests of the local people also deserve consideration. While the influx of tourists to the Arctic emphasises increasingly commercial relationships with the Inuit, a more traditional interaction still can be sought. Expeditions that plan to operate through a settlement should remember that the simple diplomacy of formally requesting permission from the Town Council in advance can be of tremendous aid.

EXPEDITIONS 1967-1987: A PERSONAL ACCOUNT

Cape Dyer Region: 1967 and 1977

My interest in the Arctic began about 1965 with the revelation that Nordair ran scheduled flights to Frobisher Bay with monthly flights to the radar site at Cape Dyer on the Cumberland Peninsula of Baffin Island. Reading of expeditions to Pangnirtung Pass, I wondered what new mountains might be approached from Cape Dyer. Being familiar with the Canadian map and aerial-photo system from a prior expedition to the British Columbia Coast Range (Cochran 1958), I soon identified an objective lying north of Tilman's Mount Raleigh. Two Britishers had approached the area by walking from Cape Dyer and had named some topographic features (Gribbon 1961), but there were thousands of square miles of virgin territory left.

Getting there became a challenge. Then, it was particularly difficult for an outsider to find out how things were accomplished in the Arctic, but little by little, a plan emerged. Our *1967 Cape Dyer Arctic-Alpine Expedition* flew to Frobisher Bay and chartered a DC-3 to Broughton Island, the nearest settlement. On the way, we were treated to a spectacular, glacier-level flight directly through Pangnirtung Pass (Figure 1). On Broughton Island we were helped immensely by the then settlement manager Bob Pilot, who arranged for us to charter a 20-foot (6-m) whaleboat crewed by two highly-competent Inuit. They nursed the ancient, 6 hp Acadia make-and-break engine 70-80 miles (110-130 km) south to the head of an unnamed fiord. Once there, Mosesee Audlakiak and Ikalik Kokstak left with a promise to pick us up a month later, after we had crossed to the head of Sunneshine Fiord leading to Cape Dyer (named after one of John Davis's ships). We had no radio, and although we could have walked out to Cape Dyer in an emergency, we hailed the timely arrival of Mosesee after his 100-mile (160-km) journey through Davis Strait.

On this expedition we explored a large glacier system to its head, linking with the areas reached by our predecessors - Tillman (1963) to the south and Gribbon (1961) to the east.

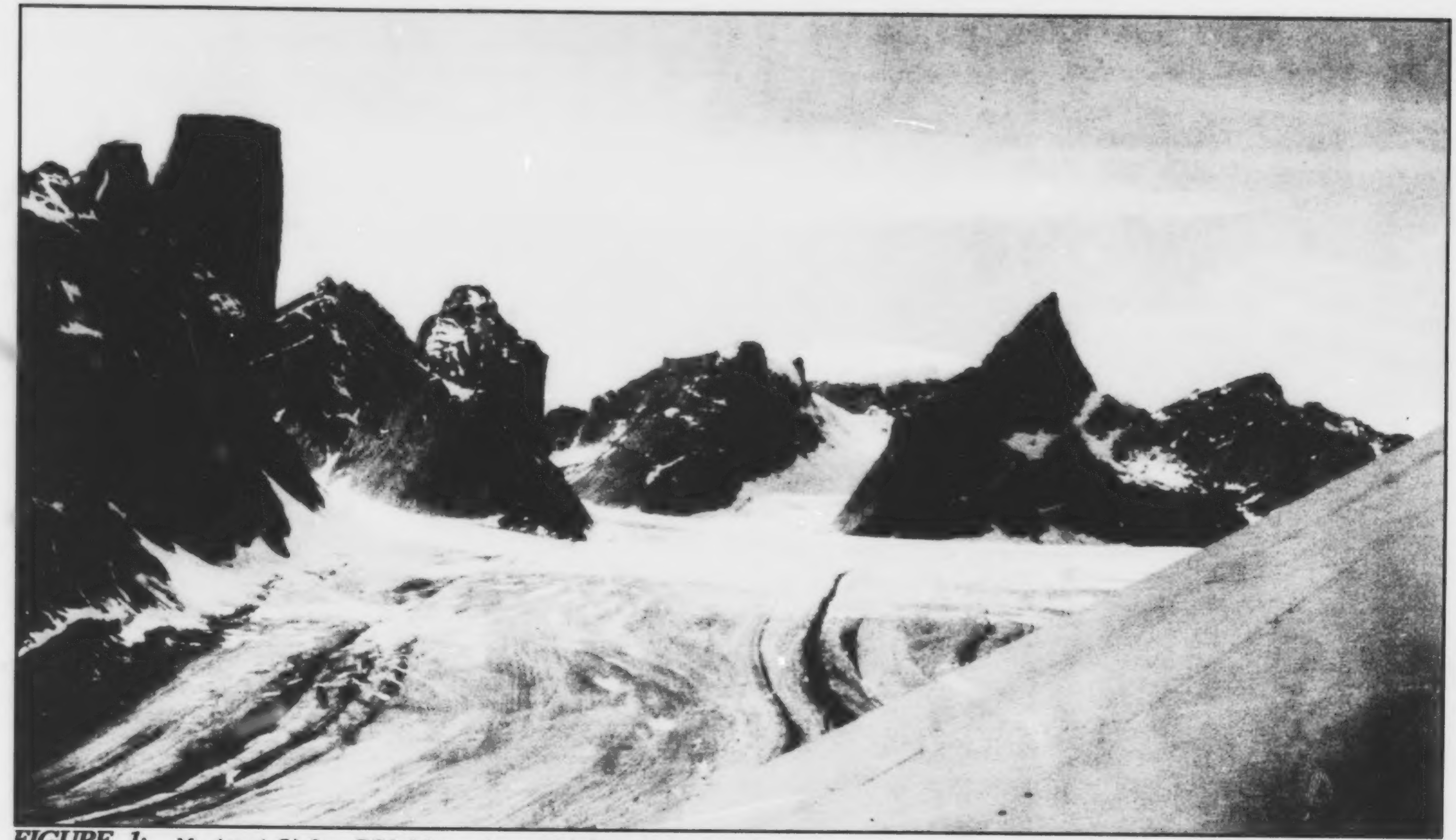


FIGURE 1: Mt. Asgard (L) from DC-3 (wing on lower right) flying through Pangnirtung Pass, 1967.

Also, we achieved seven first-ascents and named such features as: Southwind Glacier, Southwind Peak, The Mitre, Delta Peak, and others later accepted by the Canadian Permanent Committee on Geographic Names (Figure 2) (Cochran and Ritterbush 1968; Cochran 1969). In addition, we obtained a series of glacier-survey photos for the Glacier Inventory of Canada.

In 1977 our five-man *Virginia Glacier Expedition* flew directly to Cape Dyer carrying inflatable boats, which we used to reach the head of Sunneshine Fiord (Cochran 1978A). From there, we retraced our steps inland (where bears had destroyed our cache), climbed several new peaks and once more carried out a photographic glacier-survey under a contract from the Glacier Inventory of Canada. Then we embarked on 100-mile (160-km) journey southward along the coast. The method of boat travel on this expedition was notable for its fuel-economy and portability. We carried ourselves, with all gear and fuel, in two 12-foot (3.6-m) Avon inflatable dinghies powered by 3 h.p. Seagull engines. Reaching the head of an unnamed fiord between Totnes Road and Clephane Bay, we worked inland to locate and climb two peaks whose summits we had photographed and triangulated from 40 miles (65 km) away while climbing in 1967.

Baffin-Kingnait Expeditions: 1972 and 1973

The first of these ventures involved a dramatic boat trip to Kingnait Fiord, this time with my wife as one of us. Originally our goal had been Clyde River. In fact, our one-man advance party with much of our gear, had reached Clyde on a "scheduled weekly" flight from Frobisher Bay (now Iqualuit). Trouble began when the rest of us arrived in Frobisher Bay for the next flight and were told we would be lucky if there were one in a month. Reluctantly, we borrowed gear, and flew to Pangnirtung and our secondary objective north of Kingnait Fiord. Inevitably it was again about a 90-mile (145-km) boat trip from the settlement.

With the help of Ross Peyton, owner of the first hotel in Pangnirtung, we chartered a freighter canoe. After a radiotelephone call to our friend in Clyde (who announced wistfully that he had begun to train local climbing-partners), we set off on an epic voyage to Kingnait with two Inuit. The first evening we hit a floating chunk of ice at full speed, knocking a hole in the bow and nearly upsetting. We struggled through heavy pack ice for two days. Then our last (and nearly terminal) accident occurred in open water, when

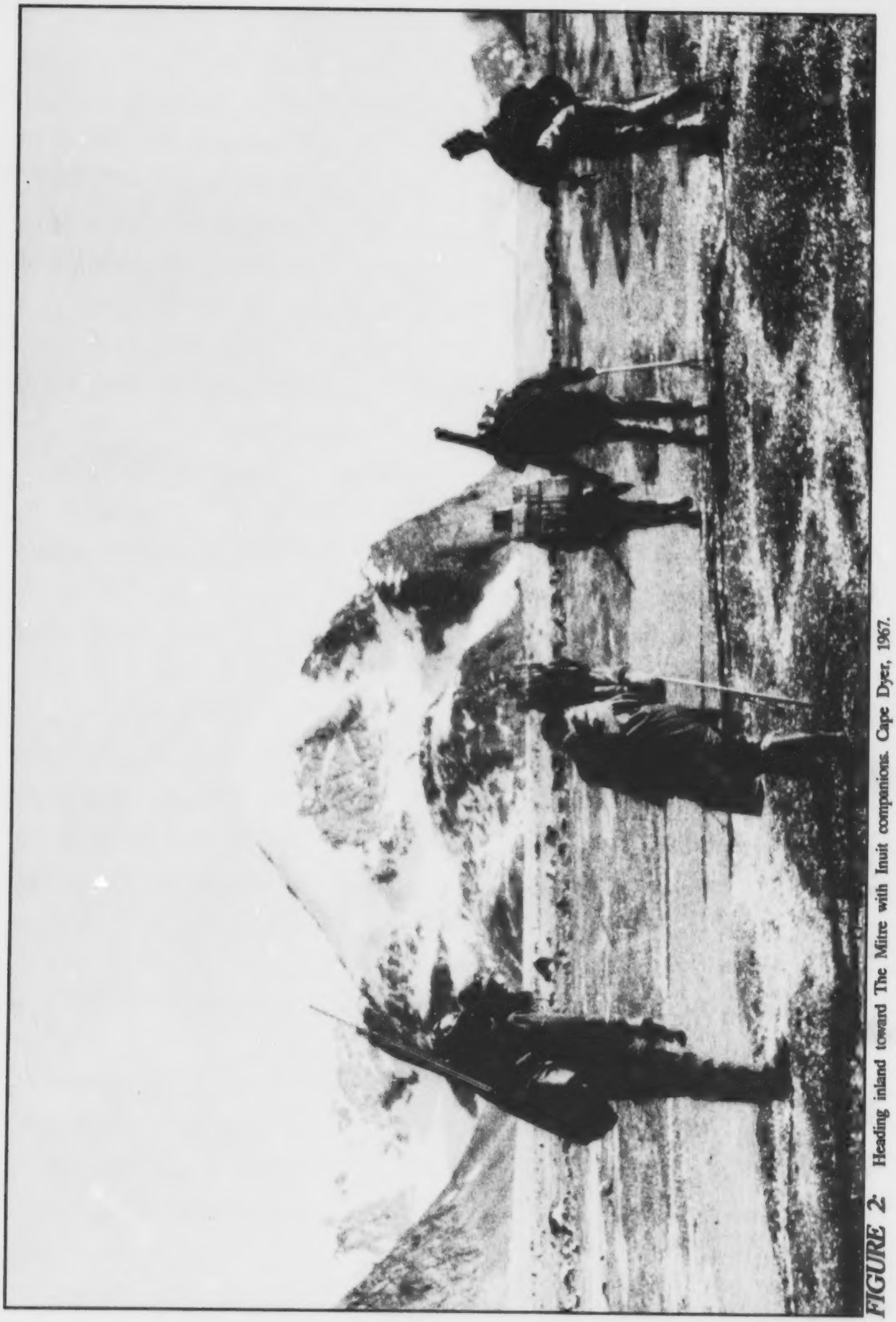


FIGURE 2: Heading inland toward The Mitre with Inuit companions. Cape Dyer, 1967.

following seas half-swamped us. Fortunately we were close to an hospitable shore, but we learned to respect localized, "wind tunnel" effects in northern fiords.

After landing we waved goodbye to our reckless boatmen, hoping that Ross would find someone else to pick us up. The next day we backpacked up the valley, but towards evening my wife and I became desperate to see what lay ahead. We dropped our loads and hurried excitedly to the top of an ancient moraine. There we saw the upper valley, choked by ice that was split by a symmetrically-beautiful pointed rock peak amid spectacular mountains rising from unexplored glaciers (Figure 3).

We returned to base, and the next day had started back up the valley when a Piper Cub zoomed overhead. An hour later our stranded friend appeared over a hill! He had hitchhiked (with all our gear) from Clyde with a bird-surveyor and found a landing-site nearby. Thus reinforced, we headed up-valley and after climbing two peaks, found a route onto the glacier. There we encountered a blizzard and our time ran out. Again our boat arrived on schedule, but recruits to retrieve us had been scarce after tales of our outward journey had circulated through Pangnirtung.

In 1973 our return coincided with the making of the film *Land of the Big Ice* by John and Janet Foster. Although rare in those days, a small helicopter was in Pangnirtung for the film, and we negotiated transport to Kingnait Fiord in return for supplying (somewhat tongue-in-cheek) film-footage on climbing. Thus we had plenty of time to engage in a celebration of mountaineering. Despite more than a foot of new snow, we achieved first-ascents of our main objective, Naulik Mountain (5,750 ft or 1,750 m) as well as Qilaut Mountain (6,600 ft or 2,010 m, the highest in the area), and several others (Cochran 1974; Figure 4). These and other names proposed by us were translated and finally accepted both by the local community and the Canadian Board on Geographic Names in 1980. Thus began an interesting history which was continued by a British school expedition (Harben and Barton 1974), a Canadian student expedition to the adjoining valley (Amatt 1975), a French expedition (Romain 1979), and another group in 1978 that completed most of the major technical climbs in the area (Cauthorn 1979).

North Baffin Expeditions: 1974 and 1981

By 1974, the urge to move northward resulted in our heading for Coutts Inlet in northern Baffin Island. With 12-foot (3.6-m) Zodiac boats powered by 15 h.p. outboard

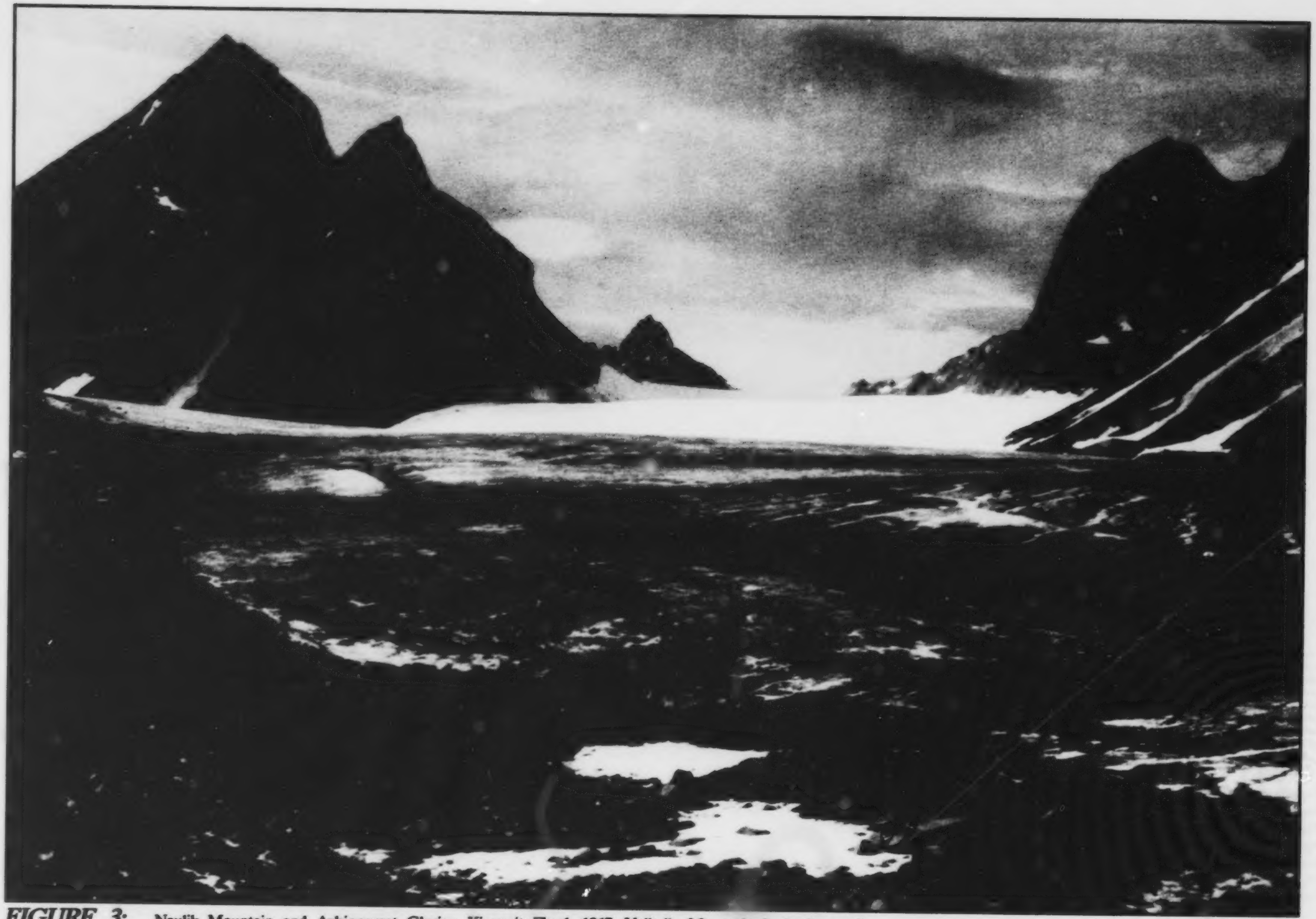


FIGURE 3: Naulik Mountain and Aybinnamat Glacier, Kingnait Fiord, 1967. Valhalla Mountain in background.

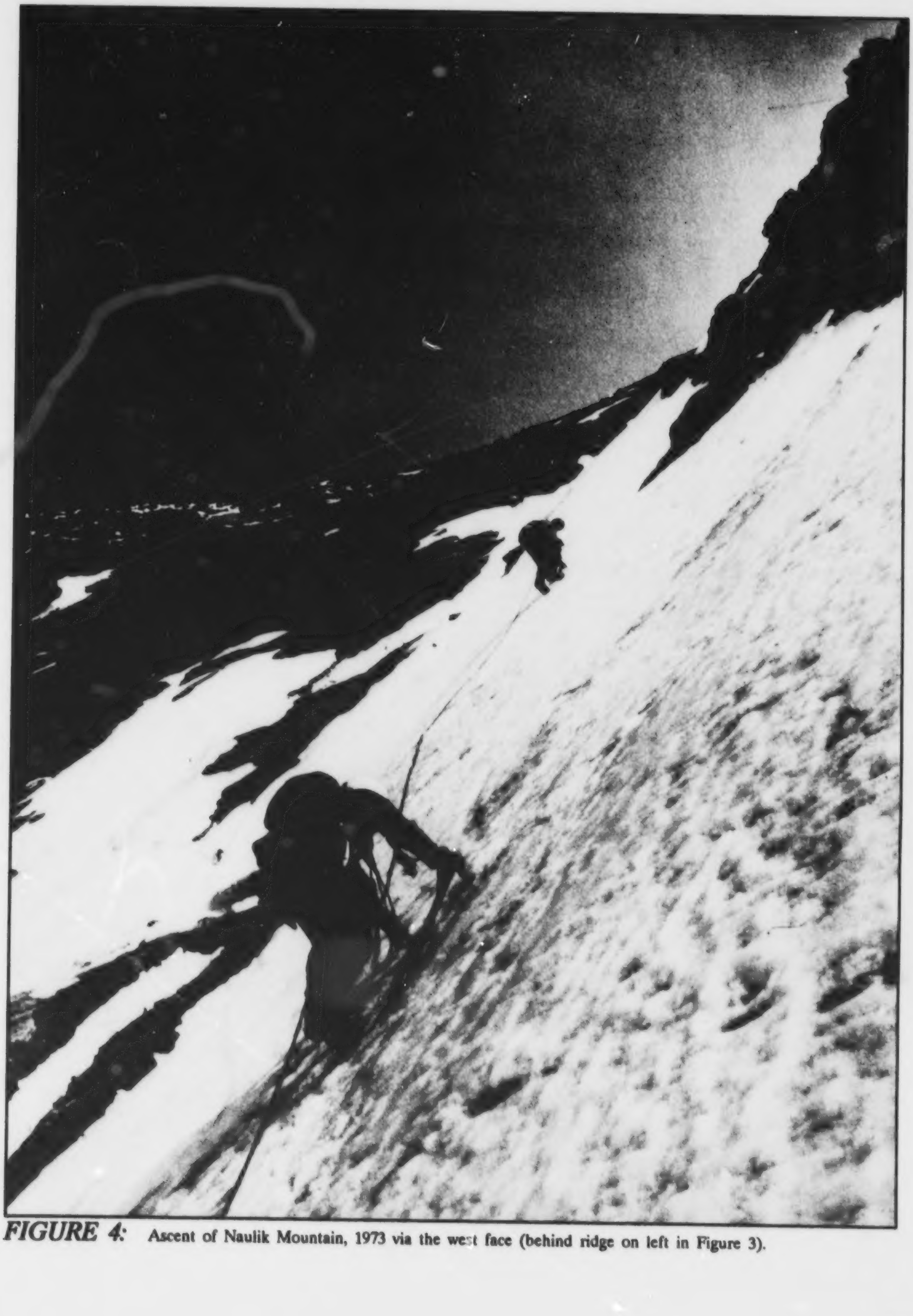


FIGURE 4: Ascent of Naulik Mountain, 1973 via the west face (behind ridge on left in Figure 3).

engines, we flew to Pond Inlet via Resolute and established camp on the beach. Soon we met Laurie Dexter, the Anglican pastor and an ardent climber, and Hermann Steltner, already a local legend, in his Arctic Research Establishment. A preliminary Zodiac trip as far as Guys Bight convinced the advance party that our plan was overly ambitious for Baffin Bay, so we hitched a ride on a large boat that was laying caches for spring polar bear surveys. Eventually, heavy ice blocked us from Coutts Inlet, and we were landed instead in Erik Harbour where some prominent inland peaks were visible from sea (Figure 5). We followed a tidewater glacier inland for 6-7 miles (about 10 km) and once again entered virgin country, although not as alpine as Kingnait. After climbing several peaks, we returned to the sea and used our Zodiacs to follow a chain of moraine lakes to additional climbs.

The boat picked us up in late August, but a storm made the trip rough. On the way to Pond Inlet, we recalled that our *North Baffin-Bylot Expedition* had not yet reached Bylot Island. So my wife, Curt Saville and I decided to rectify this omission. We gathered our gear in the dark and heaving hold, and near midnight the ship's canoe left us on a beach below the Narsarsuk Glacier, chosen as our route because it never had been ascended. Moving inland, we climbed a glorious peak (5,064 ft or 1,545 m) under perfect snow conditions (Cochran 1975; Figure 6) and were back in Pond Inlet three days later.

In May 1981 we returned for a short ski-mountaineering expedition having gained "spring" experience on Ellesmere Island in 1978. With the aid of Hermann Steltner, we spent a week testing our strain-measuring gear in sea ice, then headed for to the Narsarsuk Glacier by komatik. This time my wife and I with two companions skied 10-miles (16 km) inland to the head of the glacier and climbed Peak 5332 and another 5,000-ft (1,520 m) summit, thus completing the first exploration of this neglected corner of Bylot Island (Cochran 1982A).

The Makinson Inlet Expeditions: 1976, 1978, 1980, 1987

A fascination with the High Arctic brought us to the southeast coast of Ellesmere Island in 1976. There our map-research had identified an 1,800-foot (550-m) rock tower (Bowman Island) near the middle of Makinson Inlet. The nearest settlement was Grise Fiord, where, in 1968, Explorers Club member Lewis Cotlow had made a documentary-film on this Inuit community just before houses were built by the government. We planned to

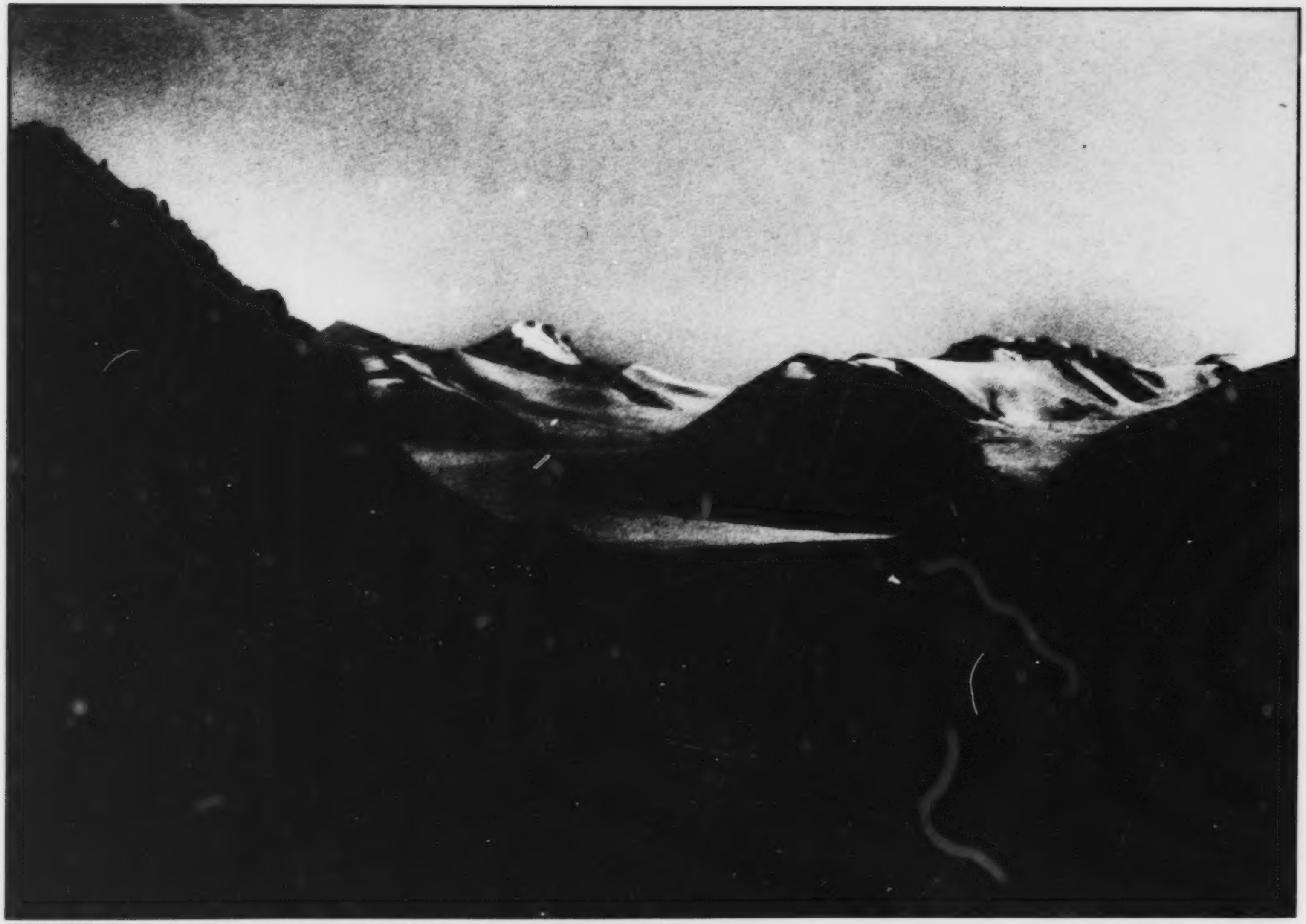


FIGURE 5: The peaks of Erik Harbour, North Baffin, as seen from the sea, 1974.

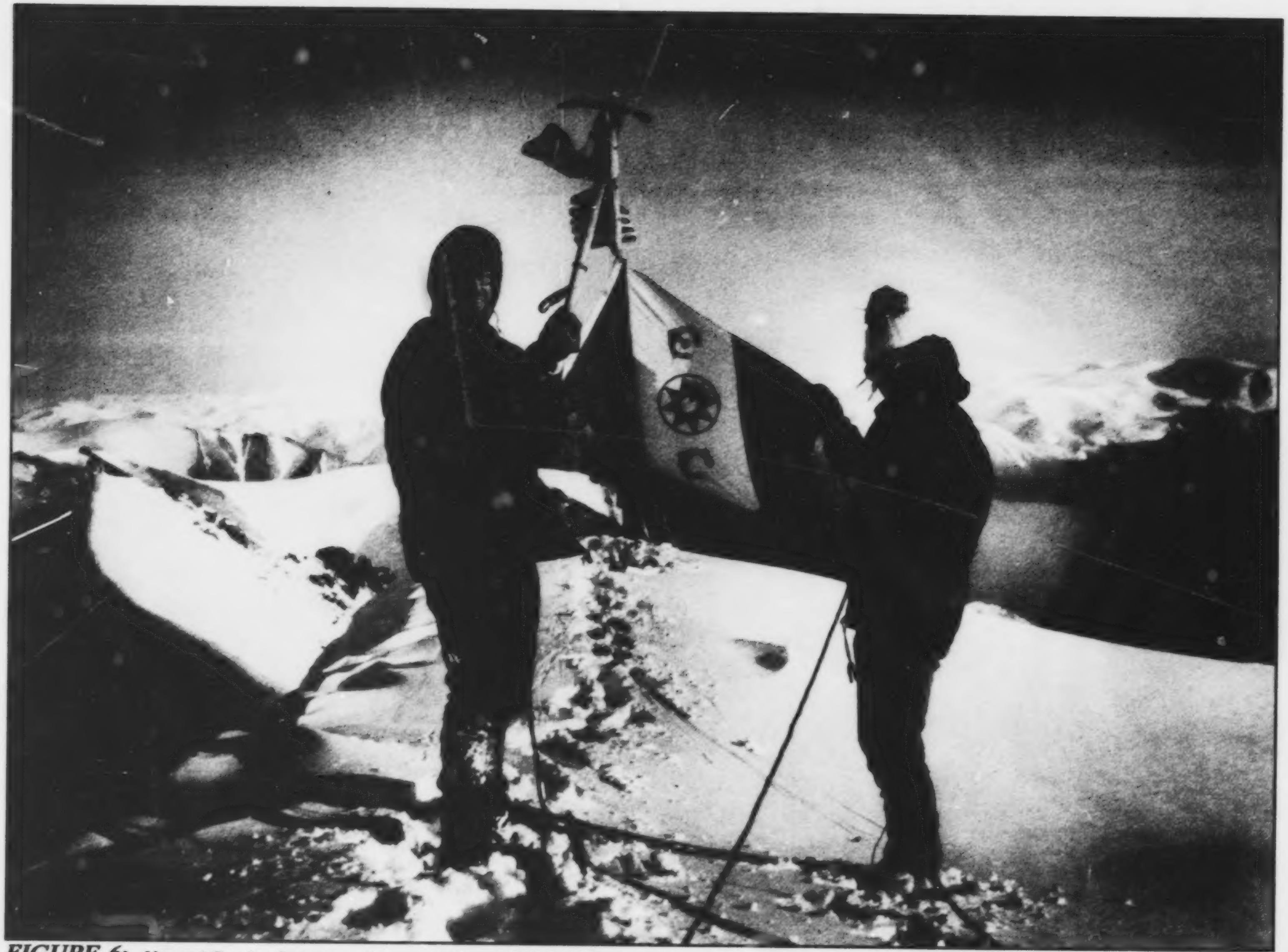


FIGURE 6: Van and Caroline Cochran on the summit of peak 5064, Bylot Island, 1974.

spend 10 days there recording the changes since Cotlow's visit, and then fly to a beach on Makinson Inlet whence we hoped to reach the island using inflatable Avon dinghies.

On this trip we brought our 16-month daughter. Once installed in our tent-camp outside town she became an immediate success and facilitated introductions, paving the way for many enduring friendships. With the aid of Laurie Dexter, we recorded many traditional Inuit songs. Curt Saville's sound-slide program on the community now is part of the permanent collections at the Haffenreffer Museum in Providence, Rhode Island.

We were then joined by Ted Whalley and his ACC contingent and flew on to Makinson Inlet, while my wife and daughter remained in Grise Fiord. We found the fiord choked with broken sea ice making the 7-mile (11-km) boat journey to the island impossible (Figure 7). Nevertheless, from our base we covered a large area, making many ascents (Cochran and Whalley 1977; Cochran 1978B).

In April 1978 we returned with our first ski-mountaineering venture in the "spring window". Our plan, arranged after months of communication with leaders of the Grise Fiord community, was to hire snowmobiles and komatiks for the trip. Our party was large, consisting of a four-man advance group followed by Ted Whalley's group of six, plus my wife a week later. This put a severe strain on the resources of Grise Fiord and required my formal appearance before a group meeting of the town hunters to negotiate their help. Then, the Grise Fiord Inuit made 14, 200-mile (320-km) round-trip sled journeys via the difficult overland route to Makinson Inlet; no more loyal or hardworking group of expedition members could ever have been found.

Riding on top of the komatiks was a wild and exhausting introduction to sled-travel. We drove at 30 mph (48 kph) into high winds at -15°C. Dragging the sleds out of deep snow, we struggled over a 1,000-foot (300-m) pass then rode downhill along boulder-strewn ravines in the dim midnight sun. After two days, we were dropped at a base-camp site in the loneliest terrain we had ever seen. We used a snowmobile to skijor (skiers drawn by a vehicle) about the inlet, enabling us to cover a wide area, and to climb the island as well as several other peaks (Cochran 1979A,B; Figure 8). Also we refined our techniques for strain-gauging sea ice (Cochran 1980). But, Makinson Inlet's peaks were no longer untouched! In 1977, officers of the Geological Survey of Canada had visited the island and other points by helicopter.

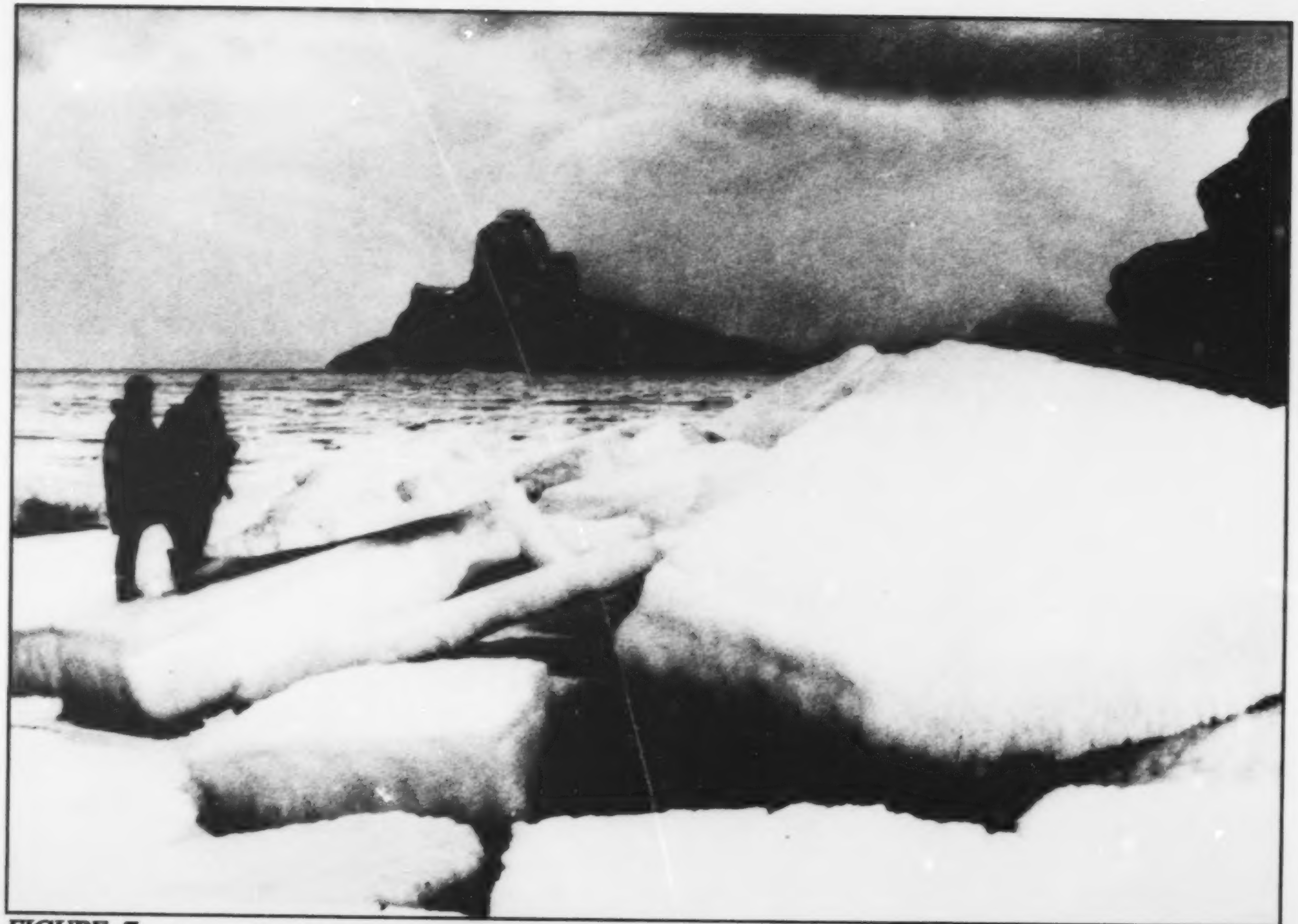


FIGURE 7: Bowman Island, Makinson Inlet, summer 1976.

FIGURE 8: Ski-mountaineering near Makinson Inlet, Ellesmere Island, 1978.

Lured by the Thorndike Peaks and Inglefield Mountains farther east along Makinson Inlet, I returned with another group, *The Inglefield Mountains Expedition*, in 1980 (Cochran 1983B). This time we brought two snowmobiles of our own and, using construction data acquired in 1978, built two komatiks in the South and air-freighted the lot to Grise Fiord. There our Inuit friends helped with the lashing, and in April we set off for Makinson Inlet, driving our own vehicles and komatiks with two supporting komatiks driven by our unforgettable coach Abraham Pijamini and a friend. If 1978 was difficult, 1980 was en eye-opener. The snow was so soft that four snowmobiles were needed to pull one load up the pass. Then we had to dig trails for hundreds of yards through the narrow ravines. Eventually, we arrived at Makinson Inlet only to find a jumbled nightmare of sea ice piled up by the fall winds and frozen in place. By now Pijamini's time off was over, and he left us with a comforting admonition: "You no watch out - you die!".

Now totally on our own, we tried route after route through the ice in fog and snow, winding back and forth, falling into holes and upending sledges. After a week we broke free near the Island (a two-hour trip on smooth ice), and later established base camp at the foot of a huge glacier leading north into the Inglefield Mountains. With barely a week left, all we could manage was an attempt on a 3,000-foot (910-m) peak at the gateway to Thorndike Peaks, and a three-day ski trip into the Inglefield Mountains, where we ascended one peak on skis and had a magnificent downhill run. On this trip we successfully used our combined sledge and backpack system for the first time.

In 1987, with satellite-photos available online at Resolute, we flew to Thorndike Peaks by Twin Otter. With limited time due to bad weather, our *Thorndike Peaks Expedition* managed a 25-mile (40-km) ski circuit of the range and made four first-ascents. So far, these four expeditions represent the only overland exploration of the peaks at Makinson Inlet (Cochran 1988).

Northern Ellesmere Island: 1982

Determined to climb north of Latitude 82°, we chose Yelverton Bay for our *Polar Mountains Expedition*. There we located several 6,000-foot (1,830-m) peaks in an area of the British Empire Range that had not been reached by earlier British expeditions. Flying direct from Resolute via Eureka, with the aid of Polar Continental Shelf Project, we had with us a snowmobile and one of our 1980 komatiks. Ambitiously, we planned climbs at several points around the bay as well as an extensive series of strain-gauge studies designed to use residual strain detection techniques to identify forces on the ice. Both plans were frustrated by yet another set of unforeseen circumstances. First, the ice was smooth but there was no wind in Yelverton Bay. This meant deep snow and difficult komatik travel. Second, the ice was the second-year variety: up to 14-ft (4.3-m) thick and not amenable to strain-gauge studies. We did manage to reach our major glacier objective, but ascending it on skis in deep snow, we encountered a maze of huge meltwater channels in the glacier - far more difficult to traverse than a crevasse-field. So, although we failed to climb the 6,000-ft (1,830-m) peaks, we did explore the glacier 16 miles (26 km) to its head, and there climbed a 5,000-ft (1,520-m) summit. Two other climbs also were made in this area (Cochran 1983).

SIGNIFICANCE

Over the years, great efforts have been expended on exploratory mountaineering in the Arctic Islands by many individuals. Aside from the personal rewards of these expeditions, they have been significant insofar as they have contributed to knowledge of the country and helped to open up new areas for recreational activities. National Parks exist on Baffin and Ellesmere islands today in places where scientists and exploratory mountaineers first walked. The Arctic has a seductive attraction that draws one back again and again. As such it constitutes a natural resource for Canada that should acquire increasing economic importance as the Arctic becomes more accessible - but hopefully never too accessible - to those who appreciate the wilderness of the unpredictable North.

ACKNOWLEDGEMENTS

I deeply appreciate the unfailing courtesy and assistance of individuals and agencies of the government of Canada and of the Northwest Territories, from senior officials to settlement managers and officers of the Royal Canadian Mounted Police. I am especially grateful to the Polar Continental Shelf Project for their logistical support on four expeditions.

Also, our Inuit friends of Grise Fiord and other settlements deserve special thanks, as do many other individuals including Jim Houston, Simon Ommanney, Hermann Steltner, Ross Peyton and Laurie Dexter. For financial aid, I thank George Wallace, The Albert Fried Foundation, The Harvey L. Karp Foundation, The Alpine Club of Canada and The Explorers Club. The expeditions were organized under the auspices of The Explorers Club and carried their traditional expedition flag.

REFERENCES

Amatt, J. 1975. Students in Baffin. Canadian Alpine Journal 58:54-55.

Baird, P.D. 1950. Baffin Island Expedition 1950: a preliminary report. Arctic 3(3):131-149.

______. 1953. Baffin Island Expedition 1953: a preliminary report. Arctic 6(4):227-251.

______. 1954. An ascent in Baffin Island. Canadian Alpine Journal 37:31-33.

______. 1964. Alpine Club of Canada Baffin camp, 1963. Canadian Alpine Journal 47:1-15.

______. 1966. Baffin Island 1965. Canadian Alpine Journal 49:28-42.

Banks, M. 1974. The uttermost North. Alpine Journal 79:174-177.

Cauthorn, D. 1979. The 1978 Northern Comfort Arctic Expedition. Canadian Alpine Journal 62:108.

Cochran, G.V.B. 1958. The mysterious plateau. Appalachia No. 126 (June):9-22.

______. 1969. South to the Arctic Circle. Explorers Journal 47:214-225.

______. 1974. Unexplored arctic mountains: 1972-73 Baffin Kingnait Expeditions. Canadian Alpine Journal 57:94-98.

______. 1975. 1974 North Baffin-Bylot Expedition. Canadian Alpine Journal 58:95-98.

Cochran, G.V.B. 1978A. Virginia Glacier Expedition 1977. Canadian Alpine Journal 61:36-38.

______. 1978B. Grise Fiord-Ellesmere Island Expedition. Explorers Journal 56:16-19.

______. 1979A. Ellesmere-Bowman Island 1978. Canadian Alpine Journal 62:22-24.

Cochran, G.V.B. 1979B. Bowman Island Expedition. Explorers Journal 57:2-7.

______. 1980. Field techniques for experimental stress analysis in arctic sea ice. Journal of Glaciology 25(91):175-182.

______. 1982A. 1981 Bylot Island Expedition. Canadian Alpine Journal 65:97.

______. 1982B. Ellesmere Island 1976-80: Makinson Inlet, Bowman Island and the Inglefield Mountains. Canadian Alpine Journal 65:38-41.

______. 1983. Polar Mountains Expedition, Ellesmere Island,1982. Canadian Alpine Journal 66:28.

______. 1988. Report of the Thorndike Peaks Expedition 1987 (Report submitted to Polar Continental Shelf Project).

Cochran, G.V.B. and P.C. Ritterbush. 1968. 1967 Cape Dyer Arctic-Alpine Expedition. Canadian Alpine Journal 51:185-198.

Cochran, G.V.B. and E. Whalley. 1977. 1976 Ellesmere-Makinson Expedition. Canadian Alpine Journal 60:11-12.

Errington, A. 1979. Broad Peak, Sam Ford Fiord, Baffin Island. American Alpine Journal 22:210-211.

______. 1983. British Empire Range, Ellesmere Island. American Alpine Journal 25:175-178.

Erskine, A. 1974. A naval expedition to the shores of the Arctic Ocean 1972. Naval Review 62:18-21. (See also Expedition Report, privately published.)

Ferris, B.J. 1955. Arctic-Alpine ascents on Bylot Island. American Alpine Journal 9(2):168-169.

Goodman, D.J. 1982. Oh! Ellesmere. Canadian Alpine Journal 65:21-24.

Gribbon, P.W.F. 1961. Climbing in the Canadian northland. Irish Mountaineering 1961:31-37.

Harben, C. and R. Barton. 1974. Arctic Canada 74: the Clifton College Expedition to Baffin Island. Clifton College, Bristol. 72 pp. (Privately published report).

Hattersley-Smith, G. 1962. Ellesmere Island. Alpine Journal, 67:164-165.

______. 1970. Barbeau Peak. Canadian Geographical Journal 80(3):86-91.

______. 1974. North of Latitude Eighty. Defence Research Board, Canada, Ottawa. 121 pp.

Kelly, R. 1978. Bylot Island Expedition 1977. Canadian Alpine Journal 61:44-45.

Langford, R.E. 1962. The Cambridge Arctic Canada Expedition to Cumberland Peninsula, Baffin Island. Alpine Journal 67:97-110.

MacAdam, D.P. 1981. Island hopping at Padle Fiord, 1979. Canadian Alpine Journal 64:10-15.

Moore, A.W. 1936. The sledge journey to Grant Land. Oxford University Ellesmere Land Expedition III. Geographical Journal 87:419-427.

Muston, A.J. 1974. British Army Axel Heiberg Expedition, (Princess Margaret Range). Canadian Alpine Journal 57:93-94.

O'Connell, K. and E. Whalley. 1978. Baffin '77. Canadian Alpine Journal 61:50-52.

Romain, G. 1979. Expedition Dijonnaise à Kingnait Fiord 1978. Canadian Alpine Journal 62:104-105.

Scott, D. 1973. Mt. Asgard. Alpine Journal 78:85-88.

Tilman, H.W. 1964A. In: Mischief in Greenland. Hollis and Carter, London. pp. 160-167.

______. 1964B. A crossing of Bylot Island. American Alpine Journal 14(1):205. (See also pp. 47-62 in Mostly Mischief. Hollis and Carter, London. 1966.)

Whalley, E. 1974. Baffin Island 1973. Canadian Alpine Journal 57:22-30.

______. 1980. Baffin Island ACC climbing camp 1979. Canadian Alpine Journal 63:29-32.

Williams, S. 1980. Report of the Joint Services Expedition to Princess Marie Bay, Ellesmere Island, 1980. Directorate of Naval Physical Training and Sport, U.K. (Privately published).

Wordie, J.M. 1935. An expedition to Melville Bay and N.E. Baffinland. Geographical Journal 86:297-316.

Illustrated by Brenda Carter

INDEX

A

Aberdeen, 770
Abies, 114, 117, 429
acanthodian (fossils), 62, 63, 68
Acartia longiremis, 220
Acciptridae, 522
Acer, 115
acid rain, 284
acipenserid (fish fossils), 86
acoustic sounding, 256
Acrodus, 82
active layer, 171, 192, 195, 200
adaptations (insect), 451
Adelaide Peninsula, 610, 611
Advance, 760
Advisory Committee on Northern Development (ACND), 9
Aegialia, 122
aerial game surveys, 369, 635
aerial photography, 232, 811
aerial surveys, 6
aeronomy, 47
aestivation, 486, 490, 495
Africa, 550
Agassiz Ice Cap, 270, 345
agnathans, 63, 74, 75
Agonum bicolor, 122
Ahti, Teuvo, 389
aircraft, 7
Akpatok Island, 387
Alaska, 32, 34, 82, 85, 86, 93, 163, 176, 269, 358, 472, 480, 481, 525, 531, 667, 672, 673, 678, 679, 680, 681, 686, 687, 691, 693, 695, 699, 702, 706, 716, 732, 733, 738, 754, 757, 759
Alaska (North Slope), 86
Alaska Highway, 27, 34
Alaska Native Land Claims Settlement (1971) Act, 34
Alaskan Inuit, 30, 34
Alaudidae, 527
albedo, 310
Albert Edward Bay, 593
Alcidae, 527, 531
alder, 429
Aldrich, J.W., 519
Alectoria minuscula (Pseudephebe minuscula), 395
Alectoria nigricans, 396
Alert, 7, 142, 146, 283, 299, 341, 345, 390, 475, 546, 547, 548, 549, 550, 553, 555, 556, 558, 559, 563, 564
Alert, 386, 761
Aleutian Islands, 34
Aleuts, 34
Alexander, 385, 758, 772
Alexandra Fiord, 166, 175, 341, 491, 499, 687, 688, 691, 693, 794, 797, 799, 801, 802
Alexandra Fiord Lowland, 487, 489, 506
algae, 7, 173, 174, 178, 182, 216, 480
Alle alle, 143, 527
Allen's Rule, 478
alligator, 98
Allognathosuchus, 96, 98
Alnus crispa, 432
Alnus incana, 115
Alnus, 101, 429, 430, 437
Alopecurus alpinus, 357, 358, 377, 434, 436, 647
alpine azalea, 432, 728
Alpine Club of Canada (ACC), 808, 824
Alpine Tundra region, 474
Alps, 308
Amadjuak Lake, 322, 725, 726, 728, 731, 734
Amadjuak River, 734
Amatt, John, 809
Amazonia, 273
Amblystegium tenax, 125
Amblystegium, 119
Amelanchier, 430
Amelanchier alnifolia, 437
amphiaspids, 69, 70
amphipods, 217, 223, 224, 225
Amund Ringnes Island, 86, 367
Amundsen Gulf, 670, 759
Amundsen, Roald, 26, 37, 387
Anacites, 117
Anadyr Peninsula, 754
Anadyr River, 754
anaerobic zone, 199
Anas acuta, 522
anaspid (fossils), 59, 65, 66, 75
Anatidae, 522
Anchorage - Fairbanks railway, 34
Anderson, Dr. R.M., 37, 763, 764
Andes (Argentina), 308
Andromeda polifolia, 432
Anglican Church, 809, 824
Anisian-Karnian (time), 82
annuals (plants), 426
Anser albifrons, 522
Antarctica, 162, 189, 191, 211, 250, 284, 756, 797, 806
Antennaria compacta, 434
anthomyiid flies, 459, 460
Anthus spinoletta, 528
Antwerp, 257
aphids, 456, 460
aptery, 454
Aptian-Albian (age), 85
aquatic sedges, 422
Aracispermum, 118
Aracites, 118
archaeological dating, 164
archaeologists, 667, 669
archaeology, 49, 591, 666, 670, 673, 675, 678, 679, 680, 687, 691, 693, 707, 708, 709, 710, 717, 718, 726, 732, 733, 734, 738, 739, 799, 801
Arctic (D.G.S.), 570, 763
arctic adaptations (crane flies), 478
arctic avens, 432, 497
Arctic Basin, 223, 321
Arctic Bay, 387
Arctic Biological Station (Fisheries and Oceans Canada), 718
Arctic Biome, 518, 519
Arctic Buoy Program, 321
arctic char, 728
Arctic Circle, 98, 797, 808
Arctic cod, 218
arctic fireweed, 434
arctic fox, 168, 170, 176, 177, 462, 481, 574, 660, 691
Arctic front, 426
arctic hare, 574, 575, 584, 643, 646, 662, 691
Arctic haze, 45, 284, 337
Arctic Ice Dynamics Joint Experiment (AIDJ[illegible] 1
Arctic Institute of North America, 571, 581, 80[illegible]
Arctic Institute of North America Expedition (1953), 807
Arctic Meteorology Section (Canadian Climate Centre), 340, 343
Arctic Ocean, 46, 49, 107, 206, 222, 249, 275, 297, 304, 308, 310, 311, 319, 332, 341, 476, 744, 746, 748, 751, 753, 754, 756, 757, 760, 761, 773
Arctic Ocean (air), 311

---

* *To gather all references to plant and animal species, please refer to both their common and scientific names.*

Arctic Ocean (ice), 224, 319
Arctic Ocean Basin, 746, 748, 762
"Arctic outbreaks", 289
Arctic Pilot Project (APP), 28
Arctic refugia, 476
Arctic Research Commission (U.S.), 16
Arctic Research Establishment (Pond Inlet), 824
arctic sovereignty, 345
arctic white heather, 432
"Arctic Wildlife", 569
arctic willow, 367, 432, 488, 497
arctic wolf, 576
Arctic Zone, 519, 524, 525, 526, 527, 530, 531
Arctic (M.V.), 257, 570
Arctophila fulva, 435
Arctosaurus, 82
Arctostaphylos uva-ursi, 430
Arenaria interpres interpes, 531, 553
Arenaria interpres morinella, 553
Arenaria interpres, 525, 544
Arenaria, 654
Argentina, 85
Arnica alpina, 434
arthrodires, 67
arthropods, 451, 454, 457, 458, 459, 460, 462, 465
artifacts, 686
arums, 117
Ash, S.R., 82
Asia, 98, 125, 355, 524, 667, 751, 752
Asio flammeus, 527
aspen, 429
Assistance Harbour, 773
Assistance, 760, 768, 772, 773, 785, 786
Association of Canadian Universities for Northern Studies (ACUNS), 16
Aston Bay, 711, 712. 715, 716
Astragalus, 374, 434, 435
astronomy, 754, 758
Athapascans, 34
Atlantic Ocean, 275, 288, 304, 747, 771
Atmospheric Environment Service (AES), 295, 297, 299, 301, 320, 321, 322, 337, 341, 345
Audlakiak, Mosesee, 817
Aulacomnium acuminatum, 119, 120, 125
Aurora Borealis, 758
Austin, Captain H.T., 772, 773, 760
Australia, 75
Australia - Antarctic (East Gondwana), 55
Australian Aborigines, 711
Austria, 762
automatic instrumentation, 50
automatic weather stations, 7, 322, 729
Auyuittuq National Park, 807, 809, 810, 813
Axel Heiberg Island, 85, 91, 94, 98, 266, 283, 304, 310, 311, 316, 317, 319, 340, 355, 369, 370, 371, 374, 377, 389, 390, 393, 396, 475, 518, 574, 575, 619
Ayles Fiord, 237, 248, 249
Ayles Ice Shelf, 233, 237, 248
Ayr Lake, 808

B

Babington, C., 386
Bache Peninsula, 166, 175, 299, 746
Back River Lowlands, 602
Back, George, 759
bacteria, 190, 199, 214, 560
bacterial symbionts, 497, 503
Baffin Bay, 206, 257, 266, 288, 297, 301, 308, 316, 332, 343, 386, 753, 758, 775, 824
Baffin Bay (cyclone), 317
Baffin Ice Dome, 726
Baffin Island, 15, 42, 143, 148, 257, 281, 322, 327, 330, 332, 333, 335, 340, 350, 353, 367, 369, 385, 387, 389, 390, 395, 396, 423, 430, 450, 472, 475, 517, 518, 525, 527, 600, 602, 610, 611, 612, 670, 673, 675, 724, 725, 726, 731, 733, 739, 744, 746, 752, 758, 807, 808, 809, 810, 812, 814, 817, 821
Baffin Island Expedition (1950), 395
Baffin, William, 752, 753, 758
Bailey Point, 393
Baillie Islands, 140, 143, 148, 614
Baird, Pat, 807, 808
Bajocian to Volgian (age), 85
Balaena mysticetus, 141, 146, 696
Baldwin, W.K.W., 389
Ballast Brook, 117, 120, 123
Balsfjord, 558, 560
Baltic, 787
Banfield, A.W.F., 616
Banks Island, 44, 86, 105, 106, 115, 117, 120, 122, 141, 143, 149, 166, 173, 330, 336, 355, 369, 371, 373, 385, 390, 430, 450, 451, 525, 572, 593, 596, 598, 601, 610, 611, 612, 613, 614, 615, 616, 617, 680, 681, 687, 691, 705, 774, 775, 779
Banks, Mike, 810
Banks, Sir Joseph, 757
Barents Sea, 762
Barents, Willem, 748, 752
Baring Channel, 619, 620
Baringaspis dineleyi, 67
Barlow Inlet Formation, 62
barnacle (nauplii), 220
Barnes Ice Cap, 395
Barren Grounds, 667
barren-ground caribou, 367, 373, 596, 602, 612, 614, 616, 624, 724
Barrett, Paul E., 390
Barrow Strait, 57, 206, 207, 214, 219, 297, 610, 611, 617, 619, 620, 691, 758, 759, 760, 769
Barrow, Sir John, 757, 759, 778
Barry, R.G., 301, 304
Basilisk, 771
basking (insect), 487, 489, 490, 492, 495, 499, 500, 503, 504
Bathurst Island, 44, 58, 61, 146, 148, 164, 345, 371, 389, 390, 396, 475, 571, 572, 573, 574, 576, 577. 580, 581, 583, 584, 610, 616, 619, 640, 644, 645, 671, 708, 773, 785
Bay Fiord, 92, 94
Bear Bay, 633, 637, 640
bearded seals, 681
Beaufort Formation, 6, 93, 105, 106, 107, 111, 112, 115, 116, 119, 120, 122, 162, 355
Beaufort plain, 117
Beaufort Sea, 86, 141, 206, 297, 321, 673, 680, 681, 687, 691, 696, 763
Beechey Island, 163, 770, 772, 773, 782, 785, 786, 789
beetles, 445
behaviour (insect), 454, 492
behavioural adaptations (muskoxen), 571
behavioural themoregulation (insect), 485, 499
Belcher Channel, 82
Belcher Search Expedition, 82
Belcher, Sir Edward, 760, 768, 770, 771, 785, 786, 787, 789
Belgium, 257
Bell 206-B helicopter, 256, 619, 620, 621
Bellot Strait, 615, 620, 715, 759
Bellot, Lieutenant de vaisseau Joseph-René, 770, 771, 787
Bembidion (Chrysobracteon), 122
Bembidion sordidum, 122
Bergen, 746
Bering Isthmus, 45, 125, 672

Bering Sea, 672, 673, 678
Bering Strait, 678, 751, 754, 760, 762, 773, 775, 789
Bering, Vitus, 754
Beringia, 356, 369
Bernard Harbour, 593
Bernard River, 143
Bernier, J.E., 570, 573, 763
Beschel, R.E., 319, 389, 396
besselsi species-group, 477
Betula apoda, 124
Betula glandulosa, 430, 432, 437, 728
Betula, 93, 101, 114, 115, 116, 429, 430, 437, 731
Bhutan, 806
biennials (plants), 426
bilberry, 426
Binford, L.R., 710
bioclimate, 728
bioclimatic indicators, 438
bioclimatic zones, 424, 426
biogeochemistry, 48
biogeography, 512, 728
biological oceanography, 6
biology, 42, 48, 758, 759, 763
birch, 429, 430
bird banding, 548, 584
bird breeding, 550
bird counts, 548
bird courtship, 555
bird distribution, 516
bird fauna (origin of, Canadian Arctic Islands), 530
bird migration, 546, 549, 550, 584
bird nesting, 728
bird thermoregulation, 556
Bird, Charles, 389, 393
Bird, Wing Commander Derek, 809
birds, 140, 143, 162, 177, 459, 460, 465, 558, 560, 562, 563, 568, 570, 572, 580, 733
Birnirk phase, 679, 680, 686, 687
bison, 148
bison (carcasses), 163
Bison priscus, 143
Bison sp., 141
Blaa Mountain Formation, 82
Black Guillemot, 527
Black-bellied Plover, 525
black-footed ferret (carcasses), 163
Black-legged Kittiwake, 526
Blake, Weston, Jr., 393
Bliss, L.C., 423
blizzards, 578
blood-sucking insects, 612
blow flies, 460
blueberry, 426
Bluefish River, 369
bluegreen algae, 357, 374, 375
Boas, Franz, 725
boat-nails (Norse), 673
boats, 677
body condition (birds), 556, 559
bog laurel, 430
"bone-bed" (accumulation of fossils), 63
Boothia Peninsula, 423, 434, 517, 519, 596, 602, 610, 611, 615, 617, 620, 621, 702, 718, 759
Boothia Uplift, 59, 61, 62
Boothiaspis, 66, 74
Borden Island, 367, 616, 619, 764
boreal forest, 119
Boreal Forest-Tundra region, 474
Boréal, 789
Borup Fiord, 645, 646, 647, 654, 660
bow-and-arrow, 667, 669, 672
bowhead whale, 141, 146, 672, 680, 681, 685, 696, 697, 699, 702, 704, 705, 706, 707, 708, 711, 712, 716, 717, 718
Bowman Island, 824
brackish marshes, 367
Brant, 522
Branta bernicla, 522
Branta canadensis, 522
Brassard, Guy, 390
break-up, 219
breeding (birds), 519, 546, 549, 553, 558, 560, 562, 563, 564, 569
Brest, 769
Bridgerian (time), 94
Bridport Inlet, 773, 775
Britain, 71, 549, 562, 744, 753, 769, 770
British Admiralty, 754, 757, 758, 771, 787
British Columbia, 308, 310
British Empire Range, 810, 830
British Museum (Natural History), 387
British Parliament, 758
Brittany, 744
Broad Peak, 810
Brock Island, 367, 616, 619, 764
Brock, R.W., 37
Brodo, I.M., 389, 390
brontothere, 94
Bronze Age, 672
bronze trader's balance (Norse), 673
Brooman Point, 6, 164, 168, 170, 171, 172, 174, 175, 178, 180, 708
Broughton Island, 817
brown bear, 612
brown hare, 662, 644, 663
Brown, R.J.E., 343, 345
Browne Island, 256
Brunisols, 355
Bryam Martin Island, 785
Bryobrittonia longipes, 125
Bryobrittonia, 119
bryophyte (fossils), 116
bryophytes, 119, 358
Bryson, R.A., 304
Bryum pseudotrichetrum, 120
Buchan, Captain John, 757
bumblebees, 456
Burden, Elliot, 88
Burton, R., 645
Burwash Bay, 729, 731, 732, 734
butchering, 704, 712, 717
Buteo lagopus, 522
buttercups, 174
butterflies, 454, 457, 459, 460
Byam Martin Island, 616, 618, 640
Bylot Island, 88, 610, 611, 612, 807, 808, 809, 824
Bylot, Robert, 752, 758
Byrd, Richard E., 797, 799
Byron Bay, 593

C

C-Tech (fish-finding sonar), 257
Calanus glacialis, 220
Calanus hyperboreus, 219
Calcarius lapponicus, 528
Calidris alpina, 525
Calidris canutus canutus, 531, 550
Calidris canutus islandica, 550, 553
Calidris canutus rufa, 550
Calidris canutus, 525, 544
Calidris minutilla, 525

Calliergon giganteum, 119, 120
Calliergon richardsonii, 118
Calliergon, 120
Callorhinus ursinus, 598
Caltha palustris, 435
Calvert, Commander, 797
calving areas (barren-ground caribou), 614
calving grounds (Peary caribou), 579
Cambridge Bay, 281, 332, 333, 353, 573, 591, 594, 599, 600, 602, 603, 615
Cambridge University, 808
Cameron Island, 82, 85
camouflage, 451
Camp Century, 267
"Camp Clay", 799, 801, 802
Campanian - Maestrichtian (time), 86
Campylium stellatum/arcticum, 118, 119, 120
"Canada and Polar Science", 584
Canada Goose, 522
Canadian Arctic Expedition (1913-1918), 37, 141, 517, 763
Canadian Arctic Islands, 9, 13, 46
Canadian Arctic Lowlands, 55
Canadian Armed Forces, 583
Canadian Climate Centre, 295
Canadian Expedition to Study the Alpha Ridge (CESAR), 11
Canadian Hydrographic Service, 255
Canadian Inuit, 30, 31
Canadian Museum of Civilization, 47
Canadian National Collection (CNC), 471
Canadian Permanent Committee on Geographic Names (Canadian Board on Geographic Names), 816, 819, 821
Canadian Shield, 59, 430
Canadian Shipping Company Ltd., 257
Canadian Wildlife Service, 389, 579, 591
Canadian-Swiss Expedition (1950), 807
Canis lupus bernardi, 601
Canis lupus, 612
Canol Pipeline and Road, 27
Canrobert Hills, 618
Cape Anne, 715
Cape Clarence, 1
Cape Cockburn, 785, 786, 789
Cape Dalhousie, 614
Cape DeBray, 780, 789
Cape Desolation, 771
Cape Dorset, 387, 670, 738
Cape Dyer, 817, 819
Cape Fisher, 780
Cape Garry, 715
Cape Herschel, 299, 345
Cape Hopes Advance, 283, 332
Cape Hoppner, 775
Cape Horsburgh, 772
Cape Hotham, 773
Cape Parry, 614, 687
Cape Phillips basin, 57
Cape Phillips Formation, 59, 64
Cape Prince of Wales, 754
Cape Providence, 774, 789
Cape Riley, 772
Cape Russell, 618
Cape Rutherford, 802
Cape Sabine, 164, 793, 797, 799, 801
Cape Sparbo, 705
Cape Storm, 143, 146, 180
Cape Storm Formation, 59, 61
Cape York meteorite fall, 672
Carcass, 754
carcasses (frozen), 162, 163, 173, 176, 177, 182
Cardinalinae, 530
Carduelinae, 529, 531
Carduelis flammea, 529
Carduelis hornemanni, 529
Carex aquatilis, 118, 434
Carex membranacea, 377, 435
Carex nardina, 647, 657
Carex stans, 377
Carex ursina, 366
caribou, 146, 168, 171, 174, 177, 281, 370, 569, 590, 591, 592, 593, 594, 595, 596, 598, 599, 600, 601, 602, 603, 608, 609, 611, 612, 613, 614, 615, 616, 617, 618, 620, 621, 666, 671, 675, 685, 686, 697, 702, 705, 707, 708, 726, 728, 732, 733, 734, 738, 778
caribou (antlers), 166, 178
caribou (carcasses), 163
caribou calving grounds, 595
caribou marking, 618
caribou taxonomy, 596
Carter, Brenda, 1
carvings, 671
Carya, 115, 123, 124
Cassiope tetragona, 366, 432, 434, 489, 647
"Catalogue of Canadian Birds", 516
caterpillars, 451, 457
Cathay, 751, 752, 757
Catherine the Great, 754
Catoscopium nigritum, 119
Cave of Ultima Esperanza, 162
CDMS (Climate Data Management System), 297
Cenomanian -Campanian (time), 86
Central Arctic Meats Ltd., 603
Central Eskimos, 702
cephalaspids, 63, 64, 65, 70, 71
Cepphus grylle, 527
Cerastium alpinum, 358, 647
Cerastium, 377
Ceratodon purpureus, 120
Cercidiphyllum, 93
CFC 11 and 12 (chloroflourocarbons), 285
chain mail (Norse), 673
Chancellor, Richard, 752
Charadriidae, 525
Charadrius hiaticula, 525
Charadrius semipalmatus, 525
Cheese Falls, 635
chemocline, 190, 198
chemolimnion, 199
Chen caerulescens caerulescens, 728
Chen caerulescens, 522
Chen rossii, 522
Chernov, Y.I., 477
cherry, 426
Chile, 162
China, 55, 58, 69, 672, 751, 752
"Chinook", 308, 476
Chipewyan, 667
Chipman, K., 37
chironomids, 454, 456, 459
Chironomus, 456
chlorophyll, 209, 210, 211, 212
Chriss, Terry, 222
Christie, R.L., 389
Christopher Formation, 85
Chronological Station Data (AES) Catalogue, 295
Chrysanthemum integrifolium, 434
Chukchi Sea, 763
Churchill, 343, 754
ciliates, 214
cimoliasaurids (plesiosaurs), 86
cimolichthyids (fish fossils), 86
Cinclidium arcticum, 126

Cinclidium latifolium, 126
Cinclidium, 119
cinnabar moth, 503
Civita Vecchio, 769
Clamgulchian (time), 123
Clavus, Claudius, 746, 747
Clangula hyemalis, 146, 522
Clements Markham Inlet, 232
Cleome, 114, 116, 124
Clephane Bay, 819
climate, 7, 124, 273, 476, 478, 489, 601, 668
climate database, 299
climate-impact models, 725
climatic change, 51, 276, 292, 375, 462, 487, 531, 600, 602, 603, 617, 639, 670, 672, 673, 675, 679, 680, 706, 718, 733, 739
climatology, 48, 729
cline, 553
cloudberry, 432
Clyde River (Clyde), 353, 387, 472, 807, 808, 819, 821
CO2, 285
coal, 45
coastal lowlands, 375
Coastal Range (Coast Mountains), 308
Coats Island, 527
Cobboldia, 163
Cobourg Island, 299
Cochlearia officinallis, 366
Cochran, Caroline, 824
Cochran, Van, 824
Cocked Hat Island, 802
Cockerton, D., 571
cod, 33
coelocanth (fishes), 82
cold-hardiness (insects), 455, 457, 481, 485, 492, 499
Coleoptera, 445
collared lemming, 146
Collins, H.B., 389, 705
Collinson, Captain Richard, 613, 760, 773, 786
colonization, 531
Colorado, 476
Columbia Basin, 308
Colwell Report, 16
Comfort Cove, 618
Cominco, 199
common bearberry, 430
Common Eider, 522
common juniper, 429
common Labrador tea, 430
Common Raven, 527
Common Redpoll, 529
Common Ringed Plover, 525
Commonwealth Mountain, 809
communications, 48
community planning, 49
Comptonia, 116
CONAN (contoured output from various systems), 296
Cone Island, 616
coniferous forest, 115
conodonts, 61
Conover, R.J., 6
Cook Inlet (Alaska), 122
Cook, James, 756
cooperative programs, 583
COPE, 17
copepods, 205, 218, 219, 220
Copper Inuit, 173
Coppermine, 591, 599, 624
Coppermine River, 430, 754
coral reef (fossils), 45
Cordillera (North America), 304
Cork, 787
Cornus, 426
Cornwall, 744
Cornwallis Disturbance, 59
Cornwallis Island, 6, 57, 58, 61, 62, 64, 68, 146, 171, 188, 192, 206, 256, 375, 385, 389, 390, 393, 395, 472, 610, 616, 758, 760, 769, 773
Coronation Gulf, 593, 610, 613, 705, 707, 759
Corvidae, 527, 531
Corvus corax, 527
Corylus, 101
Coryphodon, 98
Cotlow, Lewis, 824
courtship activities (birds), 548, 563
Coutts Inlet, 821, 824
Cox, J.R., 37
Craig Harbour, 299, 387
cranberry, 430
crane flies, 451, 460, 471, 475, 476, 477, 478, 480, 481
Cratoneuron filicinum, 119, 120
Crepis nana, 434
Creswell Bay, 711, 712, 715, 716
Creswell, Lt., 782
Cretaceous, 86, 93, 107
CRISP (sea ice statistics), 296
"Crocker Land", 25
Croker Bay, 772
"Crokers Mountains", 758
crossognathid (fish fossils), 86
cryoprotectants, 455, 506
cryptodire, 98, 99
cryptogams, 357
ctenaspids, 69
Cumbaa, S.L., 1
Cumberland Peninsula, 808, 809, 817
Cumberland Sound, 386
currant, 426
cushion plant-cryptogam, 359
Cyanobacteria, 357, 374, 375, 377, 378
cyathaspids, 66, 67, 69, 74
Cygnini, 101
Cygnus columbianus, 522
cyptogam-herb ecosystem, 367

D

Dactylolabis rhicnoptiloides, 475
Danish, 33, 746, 753
Darbishire, Dr. O.V., 387
Davis Strait, 288, 696, 748, 752, 758, 817
Davis, John, 752, 808
dawn redwoods (fossil), 283
DC-3 aircraft, 817
De Bray, Enseigne de vaisseau Emile Frédéric, 769, 771, 773, 774, 775, 778, 779, 780, 782, 785, 786, 787, 788, 789
"De Inventione Fortunata", 748, 751
Dealy Island, 773, 774, 775, 778, 780, 789
Dealy Island depot, 778, 782
Dease Strait, 593, 596, 613
Dease, Chief Factor Peter Warren, 759
Decodon, 116, 123
defence, 47
Defence Research Board, 809
degree-days, 497
DeHaven, E., 760, 773
Delta Peak, 819
Denison, R.H., 71
Denmark, 14, 32, 549
dercetids (fish fossils), 86

Dermatocarpon hepaticum, 357, 358
Desperate, 771
Devaney, Jon, 106
Devon Island, 59, 61, 91, 99, 101, 146, 163, 167, 275, 304, 320, 327, 330, 341, 366, 369, 370, 371, 375, 386, 387, 389, 390, 395, 396, 475, 489, 517, 525, 571, 572, 580, 581, 610, 619, 633, 640, 641, 770, 807
Devon Island Ice Cap, 46, 270, 637
Devonian, 55, 57, 69, 74, 75, 107, 111
Devonian (geological province), 55
Dexter, Laurie, 809, 824
Dezhnev, Simon, 754
Diacranum leioneuron, 125
diatoms, 205, 215
Diatryma, 96
Dickson (port), 762
Dickson Island, 762
Dickson, Barron Oscar, 761
Dickson, H. Loney, 393
Dicrostonyx torquatus, 141, 146
Diefenbaker, J.G., 14, 344
Dineley, D.L., 71
dinosaurs, 45, 86
Diomede Islands, 754
Diptera, 445, 454
Disaster Bay, 785, 786
Discovery Harbour, 761
Discovery, 386, 752, 761
Disko Ø, 771, 787
dispersal barriers, 451
Disraeli Fiord, 238, 247, 248
Distant Early Warning (DEW) Line, 27, 33, 34, 295
District of Franklin, 55
District of Keewatin, 330
District of Mackenzie, 86, 531
Ditrichum flexicaule, 119, 358
diversity (insect), 465
dog-sleds, 7, 677, 705
dogs, 670
dogwood, 426
Doidge Bay, 237
Dolphin and Union caribou herd, 593, 596, 598, 611, 613, 614
Dolphin and Union Strait, 593, 599, 610, 613
Dome, 321
Dominion Observatory, 11
Domville, Dr., 779, 786
Dorothea, 758
Dorset (longhouse), 172, 175, 178
Dorset art, 670
Dorset culture, 591, 670, 671, 672, 673, 675, 705, 732, 733, 734, 739, 802
Douro Formation, 59
Dovekie, 143, 527
Draba corymbosa, 357, 647
Draba subcapitata, 357
Draba, 356, 377, 647
drag floats, 704
Drake Bay Formation, 61, 68
Drepanocladus revolvens, 119, 358
Drepanocladus uncinatus, 120
Drepanocladus, 120
Drift Station Alpha, 223
driftwood, 180, 686, 687, 696
driftwood house, 681
Drover, George, 778
Dryas integrifolia, 359, 366, 375, 377, 432, 434, 435, 462, 489, 497, 647, 654, 728
Dryas, 115, 117, 657
Duck Hawk Bluff, 115
ducks, 546
Dunbar, Maxwell J., 1, 6
Dundas Harbour, 299, 387
Dundas Island, 343
Dunlin, 525
Dupontia fisheri, 377, 434, 436
DUST (duration, time - value statistics), 296
Dutch, 746, 748, 752, 753
Dutilly, Father Arthème, 387
dwarf birch, 430, 432, 728
"dwarf shrub species limit", 475
Dwarfed and Prostrate Shrub Zone, 432, 434, 435
Dyke, A.S., 146, 149
Dzubin, Alex, 390

E

ear-tagging, 645
Early Cretaceous, 85
East Cape (Mys Dezhneva), 754, 762
East Greenland current, 756
East Ward Hunt Ice Shelf, 236, 244
Eastern Arctic Patrols (1923, 1934, 1936), 387
Eastern Glacier, 637
Eastern Passage, 276, 283
Ecole Navale, 769
ecological barrier, 546
"ecological manoeuvres", 625
ecosystems, 51, 291, 292, 355, 356, 444, 460, 465, 475
ectoparasites, 459, 460
ectotherms, 500, 503, 505
Edge of Ice (film), 6
Edgøya, 609
education, 49
Egede, Hans, 32
Eglinton Island, 86, 618, 622, 782
Eglinton Tower, 807
El Plomo Peak, 162
Elaeagnus, 426
elasmosaurids (plesiosaurs), 85, 86
Elizabeth Island, 752
Ellef Ringnes Island, 85, 86, 106, 367, 389
Ellesmere Ice Cap, 146
Ellesmere Island, 6, 25, 36, 44, 46, 82, 86, 91, 94, 98, 118, 119, 141, 142, 143, 146, 164, 166, 168, 180, 188, 230, 249, 250, 266, 267, 277, 283, 297, 304, 310, 311, 316, 317, 319, 320, 322, 344, 345, 353, 355, 366, 369, 370, 371, 374, 377, 386, 387, 389, 390, 390, 393, 395, 396, 435, 462, 472, 475, 476, 517, 518, 519, 522, 524, 525, 526, 527, 527, 544, 546, 548, 549, 555, 558, 560, 563, 564, 565, 570, 573, 574, 575, 577, 583, 610, 616, 619, 645, 670, 672, 673, 680, 687, 688, 691, 746, 761, 762, 793, 794, 797, 807, 808, 809, 810, 814, 824
Elliott, D.K., 71
Ellis, Henry, 702
Emberizidae, 528, 531
Emberizinae, 528, 531
Embry, A.F., 82
Emerald Isle, 618, 782
Emery, Alan R., 1
Empetrum nigrum, 434, 435
enchodontids (fish fossils), 86
endemism, 102
Energy, Mines and Resources Canada, 298, 299, 343, 811
England, 85, 549, 559, 758, 760
English, 746, 747, 752
Enookalook, Joshua, 88
"enriched zone", 435
Enterprise, 760, 773, 782
environment, 45
Environment Canada, 298, 328

environmental protection, 48
environmental-impact studies, 512
enzymes, 500, 503
Eocene, 93, 94, 98, 99, 101, 102
Eosalmo , 101
Epilobium latifolium, 434, 435
Epipremnum crassum, 117, 118
Epipremnum, 117
epontic (environment), 215
epontic (organisms), 205, 206, 209, 210, 217, 218, 223
epontic primary production, 223
Equisetum, 93
Equus lambei, 141, 143
Eratosthenes, 744
Erebus and Terror Bay, 786
Erebus, 760, 769
Eremophila alpestris, 527
Eric the Red, 746
Erigeron, 434
Erigonidae, 459
Erik Harbour, 824
Erikson, Leif, 42
Eriophorum scheuchzeri, 434
Eriophorum triste, 357, 377, 434
Eriophorum tussock tundra, 438
Eriophorum vaginatum, 432
Eriophorum, 434
Erioptera (Symplecta) sp., 475, 476, 477, 478
ermine, 580
Erskine, Commander Angus, 810
Escuminac Formation, 75
Eskimaspis arctica, 67
Eskimobyen, 168, 174, 175, 178
Eskimopolis, 799, 802
Eskimos, 718
Eta Island, 614
ethnography, 724, 733, 738
ethology, 572
euphausiids, 224
euphotic zone, 224
Euramerican (Cephalaspid) Province, 71, 74
Eureka, 281, 299, 310, 341, 353, 574, 830
Eureka Sound, 101, 304, 308, 310, 319
Eureka Sound Formation, 94, 98
Eureka Sound Group, 93, 94, 98, 99, 124
Eureka Sound intermontane area, 311, 316, 317, 319
Euroamerican whaling, 702
Europe, 55, 69, 70, 82, 98, 125, 265, 385, 524, 544, 548, 550, 553, 564, 668, 672, 673, 744, 746, 747, 754, 761
European Arctic, 531
European explorers, 675
evolutionary relationships, 74
Exmouth Island, 82
Expedition Fiord, 310, 396
expeditions, 569
exploratory mountaineering, 806, 809, 810, 811, 816, 831
Explorers Club, 794, 802, 824
extinctions, 532

F

Fairbanks, 34
Falco peregrinus, 522
Falco rusticolis, 522
Falconidae, 522
Farlow Herbarium, 387, 393
feathermoss, 119
Fedorov, Ivan, 754
Felix, 760
felt leaf willow, 432
Festuca, 647
Fibrisols, 355
Fielden, Captain H.W., 386, 569
Finns, 746
fiords, 6
fir, 429
First International Polar Year (1882-1883), 569
First World War, 744
Fisheries and Oceans Canada, 255, 256, 298
fishes, 30, 505, 512, 675, 734
fishing, 512, 592, 593, 685, 712
fleas, 460
flies, 445, 451, 454, 459, 460
flintworking, 669
flower flies, 459
flowering plants, 460, 462, 569, 654
"Foehn", 308, 476
food chains, 462
food web, 226
foraminifera, 122
Forest-Tundra Transition Zone, 429, 430, 437
Fort Conger, 761, 799
40 Ar - 39 Ar analysis, 99
Fosheim Peninsula, 322, 344, 345, 393
Foster, Janet, 821
Foster, John, 821
Fox, 386
Foxe Basin, 728, 729, 758, 764
Foxe Basin Expedition, 389
Foxe Lowland, 726
Foxe, Luke, 753
foxes, 639, 708
Fram Fiord, 616
Fram Haven, 799, 802
Fram Strait, 220
Fram, 387, 762
France, 85, 753
Franco-Prussian War, 788
Franklin Expedition, 82, 163, 590, 770, 772, 773, 786, 787
Franklin Strait, 610, 620, 621
Franklin, Lady, 760, 770, 787
Franklin, Sir John, 25, 757, 759, 760, 769, 786
Franklinian Arctic Canadian terrain, 74
Franz Josef Land, 609, 761, 762
Fraxinus, 115
Freeman, M.M.R., 633, 707
freeze-up, 205
freezing-out hypothesis, 199, 200
French, 753
French (fur trade), 756
French Navy, 770
Fries, Theodore, 386
Fringillidae, 529
Frobisher Bay, 281, 705, 726, 728, 731, 733, 739
Frobisher Bay (Iqaluit), 812, 817, 819
Frobisher, Martin, 42, 744, 747, 752
Fulmarus glacialis glacialis, 522
Fulmarus glacialis minor, 522
Fulmarus glacialis rodgersii, 522
Fulmarus glacialis, 519
fungi, 462
fungus gnats, 459
fur seal, 598
Fury and Hecla Strait, 758

G

Galathée, 769
galeaspids, 69
Garrett Island, 610
Garrow Lake, 188, 189, 190, 198, 199, 200
Garry Island, 143
Gateshead Island, 593, 615
Gaul, 744
Gavia stellata, 519
Gaviidae, 519, 531
geese, 30, 283, 546, 564
genetic adaptations (insects), 457
Geochelone, 98
geographical exploration, 744
Geographical Society (London), 756
geography, 42, 44, 747, 760, 762
Geological Survey of Canada, 10, 37, 58, 106, 271, 763, 824
geology, 45, 758, 763, 764
Geomagnetic Pole, 44
geomagnetics, 37
geomorphology, 48
geophysics, 44, 754, 759
geopolitics, 46
Georyssus, 122
Gesellschaft für Erdkunde (Berlin), 756
Gilbert, William, 751
Gjøa, 26
Gjøa Expedition, 387
Gjøa Haven, 387, 614
Glacier Inventory of Canada, 816, 819
glaciers, 6, 265
Glaucous Gull, 526, 553
Glenelg Bay, 592
Glenn Highway, 34
Gleysols, 355
Glyptostrobus, 93, 115
gnathostomes (fish), 55, 63, 68, 75
gnats (fungus), 451
Godfrey, W.E., 572
Godthåb (Nuuk), 771
Good Friday Bay, 390
Government of Canada, 16, 344
government research stations, 582
Government of Canada, 763, 808
Government of Northwest Territories, 808
Government of Northwest Territories regional biologists, 583
graminoid-moss meadows, 367
Grant Land, 386
Granville, Earl, 771
graptolites, 59
grass-moss tundra, 356
grasses, 354, 480, 639, 647, 654
Gray, D.R., 571
Great Britain, 445, 754
Great Plain of the Koukdjuak, 728
Great Plains, 273
Great Whale River, 212
Greater White-fronted Goose, 522
Greece, 744
Greely Expedition (1881-1883), 386, 569, 793, 797, 799, 803
Greely, A.W., 570, 575, 799, 801, 809
green alder, 432
green algae, 375
Green Bay, 107, 116, 117, 119, 120, 123
Greenaway, K., 9
Greene, M.T., 22
Greenhithe, 768
"Greenhouse" effect, 46, 269, 271, 285, 286, 603
Greenland, 7, 14, 28, 29, 32, 33, 34, 42, 93, 188, 267, 269, 283, 284, 297, 353, 385, 386, 387, 472, 487, 518, 522, 527, 544, 546, 548, 549, 550, 573, 600, 602, 603, 610, 623, 667, 670, 672, 673, 675, 678, 688, 696, 699, 706, 738, 744, 746, 747, 752, 753, 754, 757, 761, 762, 763, 771, 797, 799, 806
Greenland Ice Cap, 761
Greenlanders, 30
Greenlandic Norse, 672
Greenpeace, 25, 28
Greenwich, 756
Grenfell, Lady, 797
Grenfell, Sir Wilfred, 794, 797
Griffith Island, 146, 773
Griffith, Captain, 773
Griffiths, F., 30
Grinnell Land, 386
Griper, 385, 572, 758
Grise Fiord, 613, 641, 794, 809, 824, 830
Grise Tower, 809
ground sloth, 162
ground squirrel (carcasses), 163
ground stone tools, 686
groundwater, 189
Growing Degree-Days, 422
growing-season, 451
Gruidae, 525, 531
Grus canadensis, 525
Gulf, 321
Gulf of Alaska, 353
gulls, 481
Gunn, A., 617
Guys Bight, 824
Gvozdev, Mikhail, 754
Gymnusa, 122
Gynaephora groenlandica, 456, 486, 487, 488, 489, 499, 500, 501, 502, 503, 504, 505, 506
Gynaephora rossii, 487, 501
Gynaephora, 455
gypsy moth, 500, 501, 503
Gyrfalcon, 522, 572, 574

H

Hadley Bay, 592
Hadley, John, 754
hadrosaur (juvenile), 88
Haffenreffer Museum (Providence, Rhode Island), 824
Halagoland, 746
Hale, Mason E., 389
half-buried (semi-subterranean) dwellings, 672, 688, 712, 717, 734, 771, 802
Haliaetus albicilla, 522
Hall Land, 761
Hall, Charles Francis, 761
halocline, 198, 247
Hamelin, L.-E., 23
Hamilton Island, 610, 619
Hamilton, Lieutenant, 771, 785
Hampson, C.G., 644
Hans Island, 390
Hantzch, B., 734
Hare, F.K., 337
hares, 575, 576, 648, 650, 657, 660, 661, 662, 778
Harington, C.R., 390, 570, 633
Harlequin Duck, 522
harpoons, 669, 672, 686, 688, 699, 704
Harrison, J., 9
Harrison, John, 754
Hart, H.C., 386

Hartnell, Thomas, 785
Harvard University, 386, 387, 393
Hattersley-Smith, G., 7, 337, 389, 582, 809
Haughton Astrobleme, 92, 99
Haughton Formation, 93, 99, 101
Haughton Lake, 101
Hayes, I.I., 386
health sciences, 49
Hearne, Samuel, 754
Hecla and Griper Bay, 779
Hecla, 385, 572, 758
Heemskerck, Jacob, 752
Heiberg Formation, 82
helicopters, 801, 810, 821, 824
Helluland, 42
helmeted muskox, 143
Helophorus, 122
Hemicyclaspis, 65
Herald Island, 763
Herald, 760
Herbaceous Zone, 436
herbivore carrying capacity, 369
herbivores, 505
Herring Gull, 526
Herschel Island, 140, 141, 143, 148, 614
Heterosoricinae, 101
heterostracan (fossils), 59, 61, 62, 63, 69, 71, 74
hibernacula, 490, 492, 499
High Arctic, 13, 27, 270, 289, 341, 350, 371, 374, 378, 422, 423, 424, 450, 454, 455, 456, 457, 462, 475, 478, 486, 487, 488, 546, 549, 555, 569, 575, 580, 581, 594, 596, 600, 611, 612, 613, 625, 645, 669, 671, 696, 706, 724, 728, 756, 794, 802, 803, 816, 824
High Arctic (climate), 301
High Arctic (ice caps), 271
High Arctic ecosystems, 374
High Arctic Research Station (NMNS) Polar Bear Pass, 173, 571, 576, 584, 645, 646
High Arctic wolf, 601
"Hikwa Lake", 731, 732
Hills, L.V., 123
Hippuris globosa, 118
Hippuris vulgaris, 435
Historic period, 667
history, 49
Histrionicus histrionicus, 522
Hoary Redpoll, 529
Hobbs, J.E., 301
Hobson's Ice Island, 236, 244, 245
Hobson, George D., 1
Holarctic Region, 98, 99, 445, 477, 518, 527, 529
hollow earth concept, 751
Holman, 591, 592, 594, 596, 599, 600, 601, 602, 614
Holocene, 120, 140, 146, 149, 268, 731, 732
Holtved, Erik, 688
Home Bay, 143
Homerian (age), 123
Hooker, J.D., 386
Horned Lark, 527
horse (carcasses), 163
Horton River, 430
Hot Weather Creek, 322
Howgate Polar Expedition, 386
Hubert, B.A., 571, 633, 635, 637
Hudson Bay, 44, 212, 283, 289, 332, 395, 430, 451, 519, 600, 667, 696, 756, 760, 763, 764
Hudson Bay route, 288
Hudson Strait, 288, 327, 332, 333, 744, 752, 753
Hudson Strait Eskimos, 702
Hudson's Bay Company, 33, 274, 753, 754, 759, 760
Hudson's Bay Company records, 717
human occupation, 7
"human volcano" hypothesis, 269
Hummel, M., 569
hunting, 594, 599
hydrography, 27, 48
Hylocomium splendens, 119
Hymenoptera (parasitic), 445, 465
Hypericum, 116
hypersaline (lakes), 188
Hypnum bambergeri, 357, 358
Hypnum hamulosum, 119
Hypogastrura concolor, 455
Hypsithermal, 148

I

Ibbett Bay, 618
Ice Age (Pleistocene), 667
ice algae, 210, 211, 212, 215, 216, 219, 220, 223, 224
ice caps, 266, 268, 518
ice cores, 240, 241, 242, 247
ice dams, 247
ice fog, 580
ice growth, 246, 249, 250
"ice pump", 250
ice islands, 230, 232, 321
ice salinity, 238, 240
ice surface topography, 233
ice thickness, 232, 244
ice-free polar sea concept, 752
ice/water interface, 219
Iceberg Bay Formation, 94
Iceberg Glacier, 396
icebergs, 257, 288
icebreakers, 7, 29
Iceland, 269, 276, 387, 544, 546, 549, 550, 558, 564, 565, 744, 746, 747
Iceland Gull, 526
ichthyodectids (fish fossils), 86
ichthyosaur (fossils), 82, 85
Icterinae, 530
Igloolik, 387, 393, 582
igloos, 703, 712
Iglutalik Lake, 731
"Immerk" (artificial island), 143
Imperial Admiralty College (Russia), 754
Independence (cultures), 172, 178, 732
Indian and Northern Affairs Canada, 298
Indians, 667, 672, 754
Indies, 751, 752
inflatable dinghies, 819, 824
Inglefield Mountains, 830
Inglefield, Edward, 760
Innes-Taylor, Alan, 389
insect (fossils), 105
insect life cycles, 456
insect phenology, 456
insects, 120, 122, 444, 445, 455, 457, 478, 486, 488, 506
inter-island migrations (caribou), 609, 616, 619, 620, 622, 623, 624, 625
intergrades (caribou), 609
internal clock (hares), 662
International Biological Program (IBP), 49, 275
International Botanical Congress (Montreal 1959), 390
International Geophysical Year (1957-1958), 49, 570
International Geosphere-Biosphere Project, 50
International Lithosphere Project, 50
International Magnetospheric Study, 50
International Polar Year (1832-1883), 49, 762, 793, 797

Intrepid Bay, 256
Intrepid Passage, 620
Intrepid, 760, 768, 771, 772, 773, 778, 782, 785, 786
Inuit, 7, 33, 34, 42, 374, 581, 583, 590, 592, 614, 615, 616, 617, 641, 666, 667, 668, 669, 672, 673, 675, 677, 693, 702, 703, 706, 708, 718, 724, 725, 733, 738, 759, 760, 771, 772, 812, 814, 815, 817, 819, 824
Inuit (carcasses), 163
Inuit communities, 584
Inuit Land Use and Occupancy Project, 591
Inuit whale bone carving, 717
Inuktitut, 512
Inuvik, 33, 582
invasions, 532
Investigator, 166, 173, 760, 773, 775, 779, 780, 782, 786
ionospheric geophysics, 47
Iqaluit (Frobisher Bay), 33, 288, 332, 333, 738, 794
Ireland, Robert, 390
Irish, 746
Iron Age, 162, 672
Irvine, Dr. William M., 794
Isabel, 760
Isabella, 385, 758
Isachsen, 10, 299, 310, 311, 316, 320, 332, 333, 341
Isachsen Formation, 85
isostatic rebound, 192, 200, 356
Italy, 748
Ivory Gulls, 526, 553

J

jaegers, 526
James Bay, 389, 430, 550
Japan, 751
JAWS (Joint Arctic Weather Stations), 27, 33, 274, 299, 337, 389, 581, 584
Jenness Island, 616
Jenness, D., 705
Jesse Bay, 141
Johan Peninsula, 793, 797, 799, 802
Johansen, H., 519
Joint Services Expedition to Princess Marie Bay (1980), 810
Jones Sound, 640, 746, 753, 763
Jones, G., 171
Jones-Lancaster Basin, 58
Joy, A.H., 577, 616
Juglans, 115
Juniperus communis, 429, 430, 437
Jurassic, 85

K

Kalmia polifolia, 430
Kamchatka Peninsula, 754
Kane Basin, 762
Kane, Elisha, 760
Kanguk Formation, 86
Kap København (Greenland), 119, 122
Kap York (Cape York), 772
Kara Sea, 752
karigi, 702
Karlsefni, 42
Karluk, 37, 763
kayaks, 670, 672, 771
Keewatin (District of), 332, 333, 335, 423
Kellett, Captain Henry, 760, 768, 773, 778, 780, 785, 787, 789
Kennedy, Clayton, 1
Kennedy, William, 770
Kent Peninsula, 593, 610, 611, 613, 624
Kevan, P.G., 373
King Alfred the Great, 746
King Christian Island, 316, 320, 367
King Eider, 522
King George III, 754
King Island, 754
King William Island, 277, 387, 602, 610, 611, 613, 614, 615, 616, 697, 718, 759
Kingnait Fiord, 809, 819, 821, 824
kinosternid, 94
Kirkwall, 771
Kitikmeot Harvest Study, 591, 596
Klengenberg, C., 593
knots, 548, 549, 550, 555, 556, 558, 559, 560, 562, 563, 564, 565
Knud Peninsula, 175, 178, 799
Kodiak Island, 598
Koerner, R.M., 340
Kokstak, Ikalik, 817
Kola Peninsula, 276, 746
Kolyma River, 754
komatiks, 814, 815, 824, 830, 831
Komoayok, D., 594
Kong Karls Land, 609
krill, 224
Kron Prins Ø, 771
"krummholz", 430, 437
Kuc, Marian, 390
Kumlein, Ludwig, 386
!Kung San, 711

L

La Poudre, 787
Labrador, 519, 667, 670, 671, 675, 746, 794, 807
Lady Franklin Bay, 570, 799
Lady Franklin, 385, 760
Lagarec, D., 1
lagoons, 377
Lagopus lagopus, 524
Lagopus mutus, 524
Lagopus sp., 141
Lake Athabaska, 668
Lake Harbour, 387
Lake Hazen, 299, 345, 390, 462, 472, 475, 549, 562, 570, 809
Lake Vanda (Antarctica), 199
Lamb, H.H., 276
Lambdotherium, 94
Lambert, Gustave, 789
Lambert, John, 390
Lancaster Sound, 101, 206, 257, 297, 610, 611, 617, 691, 753, 758, 760, 763, 772
lances, 699, 704
land connections, 94, 125
Land of the Big Ice (film), 821
landfast sea ice, 229, 230
Landing Lake 107, 112, 114, 116, 117, 120, 125
Langford, R.E., 808
Langston, W., 85
Lapland Longspur, 528
Lapland rosebay, 434
Lapointe, Pierre, 1
larch, 115, 426
large-horned bison, 143
Laridae, 526
Larix, 101, 114, 426
Larsen, Henry, 26
Larus argentatus, 526

Larus glaucoides, 526
Larus hyperboreus, 526, 553
larvae, 205
LAST (land statistics), 296
last interglacial (Sangamon), 141
Late Silurian, 74
latitudinal gradients in species diversity, 529
Lauriol, Bernard, 1
Laurussia ("Old Red Sandstone Continent"), 57, 74
Lava Camp (Alaska), 118, 122
Lawrie, A.H., 389
Learmonth site, 707
Least Sandpiper, 525
Lecanora epibryon, 357, 358
Ledum decumbens, 432, 434, 437
Ledum groenlandicum, 430, 437
Lehnert, E., 386
lemmings, 141, 148, 177, 180, 354, 460, 577, 580
Leopold Formation, 61
Lepidoptera, 487, 504
Leporidae, 101
Lepus americanus, 644, 662, 663
Lepus arcticus, 643, 644, 645, 662
Lepus europaeus, 644, 651, 662, 663
Lepus timidus scoticus, 663
Lesser Golden Plover, 525
lice, 460
lichenometry, 395
lichens, 164, 171, 173, 174, 175, 182, 357, 358, 647, 728
Liddon Gulf, 775, 782
Lievely, 771, 787
Limnaea borealis, 430
limnology, 189
Lincoln Sea, 761
Lingula (brachiopod), 61
Linnaea borealis, 437
Liriodendron, 115
Little Cornwallis Island, 188, 192, 580
Little Ice Age, 7, 356, 374, 673
living fossils, 75
Llandoverian (geological horizon), 57, 64
Lochkovian (=Gedinnian) stage of Devonian, 74
Lock Island, 620
logistical support, 581
Loiseleuria procumbens, 432, 728
Lok, 42
Lomonosov Ridge Experiment (LOREX), 11
London, 771, 787
London Basin, 99
Long, Sergeant, 793
Long-tailed Jaegers, 481, 553
Longton, Royce, 390
Lorient, 769
Lougheed Island, 367, 764
Low Arctic, 116, 120, 125, 182, 343, 350, 358, 366, 375, 422, 423, 424, 450, 474, 724, 728, 731
Low, A.P., 763
Low, Erect Shrub Zone, 430, 432, 434
Lowther Island, 610, 619, 773
Lupinus, 374
Lupoff, Richard, 751
Luzula confusa, 366, 489
Luzula nivalis, 366
Lymantria dispar, 500
Lynge, B., 385, 387, 387

M

M'Clintock Channel, 277, 615
M'Clintock, Captain F.L., 386, 760, 773, 779, 780, 782, 785, 786, 789
M'Clintock Inlet, 809
M'Clure Strait, 297
M'Clure, Captain Robert, 614, 773, 775, 787
Maahs, Earl, 1
MacDonald, Stuart D., 389, 390, 574
Mackenzie Bay, 143
Mackenzie Delta, 33, 93, 140, 188, 288, 430, 705
Mackenzie King Island, 85, 367, 390, 616, 619, 764
Mackenzie River, 288, 451
MacMillan, Donald B., 797, 799
Macoun, James, 516
Macoun, John, 516
Macpherson, A.H., 594, 615
magnetism, 47, 754
Makinson Inlet, 808, 824, 830
Malerualik, 697
Malloch, G.S., 37
mammals, 162, 459, 568, 569, 570, 574, 575, 579, 580
mammoths, 143
Mammuthus primigenius, 143
Man and the Biosphere Program, 50
man-hauled sleds, 7
Manning, T.H., 593, 615, 616
Mansel Island, 527
Margaret Formation, 94
Marie Heights, 618
marine geology, 27
marine mammals, 149, 166, 580, 583, 669, 672, 675, 678, 680, 685, 691, 697, 704, 733, 744
marine transportation, 288
Markham Bay Re-entrant, 230, 232, 237
Markham, Lieutenant Albert, 761
Marseilles (Massilia), 744
Marvin, Ross G., 793, 794, 797
Mary, 772
Masik River, 143
Maskeleyne, Nevil, 754
Mason River Formation, 86
MAST (marine weather statistics), 296, 297, 301
Mathiassen, Therkel, 697, 705
Matty Island, 615
"maxithermy", 501
Maxwell, J.B., 337, 341
Mayr, E., 531
McAdam, Dave, 809
McAllister, D.E., 390
McCartney, Allen P., 393
McCartney, Nancy, 393
McDougall Sound, 616
McDougall, G.F., 780
McGhee, Robert, 42, 168, 171, 680, 687
McGill University Climate Research Group, 340
McLellan, 772
McMillan, J.G., 763
meat, 30
meat caches, 703
Mech, L.D., 577
Mecham Island, 619, 620
Mecham, Lieutenant G.F., 775, 782
Medieval Warm Period, 672
Mediterranean, 744
Meesia triquetra, 119
megafaunal extinctions, 146
Meighen Ice Cap, 270

Meighen Island, 42, 106, 119, 120, 122, 123, 124, 162, 355, 390, 764
Melandrium affine, 647
melanin, 451
Melting Degree-Days, 422
Melville Bugt (Melville Bay), 753, 772
Melville Island, 85, 143, 367, 371, 385, 390, 393, 435, 472, 475, 569, 570, 572, 573, 580, 610, 616, 618, 622, 640, 758, 773, 774, 775, 779, 782, 785
Melville Peninsula, 385, 395, 423, 434, 517, 519
Melville South Ice Cap, 270
Memorial University of Newfoundland, 88
Menyanthes, 117, 123
Mercator (Gerhard Kremer), 42, 748, 751, 760
Mercersburg, 803
Mercersburg Academy, 793, 794, 802
Mercy Bay, 166, 173, 178, 775
Mergus serrator, 522
meromictic (lakes), 188, 190
Mesozoic, 81, 82
metabolic adaptations (insects), 458
Metasequoia, 93, 115
meteorite impact-crater, 99
meteoritic iron, 672
meteorology, 48
microalgae, 205
microbial symbionts, 491
microclimate, 167, 489, 497
Microdiptera, 116, 124
microenvironments, 167, 171, 175, 178
microflora, 462
microsites, 451, 456, 465
Mid Arctic, 422, 424, 474
midden, 685
Middle Arctic, 182
Middle Devonian, 71
Middle Miocene, 94
midges, 451, 454
midnight sun, 495, 501
midpassage structures, 668
Miertsching, Johann, 782
migrations, 486, 548, 564, 565, 593, 608, 609, 613, 616, 617, 624, 680, 691, 693, 708, 732
Miller, F.L., 373
Miller, Norton, 393
Milne Fiord, 238
Milne Glacier, 238, 810
Milne Ice Shelf, 230, 233
Milne Re-entrant, 233, 236
Milton College (Wisconsin), 386
mines, 48
Minto Inlet, 592, 593, 594, 596, 601
Minuartia rubella, 357
Minuartia, 356, 377
Miocene, 91, 93, 101, 102, 123, 162, 355
Miocene (vertebrates), 99
Mischief, 808
Mitchell, Edward, 718
mites, 444, 445, 454, 456, 459, 460, 465
Mitimatalik, 697
Mixosaurus, 82
Mneme, 116
Moberly, Walter, 775
Mokka Fiord, 92, 94
Mokka Fiord Formation, 94
mollusc (shells), 180
molting, 490, 503
monimolimnia, 188, 199
Monodon monoceras, 146
Montreal, 794, 812
Moore Island, 610
Morgan, Thomas, 786
Morrison, D.A., 707
Morus, 115
Morychus, 122
mosasaurs, 86, 88
mosquitoes, 445, 454, 455, 456, 637, 734
mosses, 112, 119, 124, 125, 165, 172, 178, 180, 354, 357, 358, 375, 378, 480, 646, 647, 728, 732
Motacillidae, 528, 531
moths, 451, 459, 460, 506
Mould Bay, 106, 195, 299, 310, 311, 341, 341, 472
Mount Asgard, 807
Mount Barbeau, 807, 809, 810
Mount Mischief, 808
Mount Oxford, 809
Mount Queen Elizabeth, 807
Mount Raleigh, 808, 817
Mount Thule, 808
Mount Whisler, 809
mountain ash, 426
mountain avens, 728
mountain hares, 663
mountain heather, 432
Müller, F., 343
multidisciplnary research, 762
multiple thermoclines, 198, 200
Muscicapidae, 527, 531
Muscidae, 459
muskoxen, 6, 143, 146, 163, 165, 170, 173, 177, 178, 367, 369, 370, 371, 378, 569, 570, 571, 577, 578, 581, 583, 590, 591, 592, 593, 594, 595, 596, 598, 599, 600, 601, 602, 603, 635, 637, 639, 640, 641, 675, 680, 691, 732, 773, 775, 778, 785
mycetophylids, 459
Myrica eogale, 119
Myrica gale, 118, 119, 430, 437
Myrica, 117, 118

N

Nams, Marjorie L., 393
Nanisivik, 257
Nansen Ice Plug, 230, 241, 246, 249
Naples, 769
Napoléon III, 787
Napoleonic Wars, 754, 757
Nares Expedition, 146, 386
Nares Strait, 297, 753, 760, 761, 762
Nares, Captain George S., 141, 761, 768, 771, 789
Narsarsuk Glacier, 824
narwhals, 15, 146, 164
National Air Photo Library (Ottawa), 328, 811
National Defence Canada, 298
National Film Board of Canada, 6
National Geographic Society, 794, 799, 802
National Museum of Natural Sciences (Ottawa), 47, 140, 387, 389, 393, 512, 572, 581, 584
National Museums of Canada, 58, 298
National Research Council of Canada, 343
National Science Foundation (U.S.), 16
National Topographic Series, 811
natural selection, 503
"nature observatories", 7
Naujan, 697
Nauiik Mountain, 821
navigation instruments, 754
Nearctic, 476, 477, 501, 518, 528, 531, 546
Nebria, 122
Nechuka Plateau, 308

needle cases, 688
Nelson River, 681, 685, 686, 691, 693
Nelson River site, 687
Nelumbo, 93
nematodes, 205
Neo-Atlantic period, 706, 733
Neo-Boreal period, 706
Neo-Eskimos, 667, 672, 679, 732, 733
Neolithic, 667
Neoplagiaulax, 96
Neotropical, 530
Nephrotoma lundbecki, 474
Neptune, 763
nesting areas, 555
Netherlands, 118, 748, 752
Nettilling Lake, 322, 725, 728, 729, 731, 734
New Siberian Islands, 761, 763
New World, 564, 667
New Zealand, 308
Newfoundland, 519, 524, 643, 668, 670, 678, 746
Newman Bay, 573
Newman Smith Lowland, 637
Nicholas of Lynne, 748
1983 Ellesmere Island Arctic Expedition, 803
1967 Cape Dyer Arctic-Alpine Expedition, 817
nocturnality, 99
Nome, 34
non-renewable resources, 48, 299
Nordair, 817
Nordenskjöld, Baron A.E., 761
Nore, the, 771
Norman Wells, 343
Norse, 7, 673, 744, 746, 747, 760, 799
North America, 125, 265, 355, 478
North American Arctic ecosystem, 422
North American Element, 531
North Atlantic Ocean, 673, 746, 757
North Atlantic Treaty Organization (NATO), 28
North Baffin-Bylot Expedition, 824
North Cape, 746
North Magnetic Dip Pole, 44, 759
North Pacific Ocean, 754, 756, 757
North Pangnirtung Fiord, 808
North Pole, 11, 42, 512, 590, 747, 748, 751, 754, 757, 758, 761, 762, 789, 797, 812
North Slope (Alaska), 34, 36
North Star, 768, 772, 773, 782, 785, 786, 787
North Water, 316, 317, 320, 343, 772, 797
North Water Project, 343
North-East Passage, 761
North-West Passage, 47, 163, 206, 288, 289, 344, 569, 590, 752, 752, 754, 756, 757, 758, 759, 760, 769
Northern Boreal Forest Zone, 426
Northern Fulmar, 519
Northern Heritage Foundation, 583
northern Labrador tea, 432, 434
Northern Oil and Gas Project (NOGAP), 341
Northern Pintail, 522
northern rose, 430
Northern Wheatear, 527, 530
Northwest Territories, 289
Northwest Territories, Department of Renewable Resources (Northwest Territories Wildlife Service), 591, 594
Northwest Territories Government regional biologists, 572, 584
Norway, 14, 546, 549, 550, 555, 558, 560, 564, 595, 603, 744, 746, 761, 762, 763
Nostoc commune, 375
Nouveau Québec, 32
Nova Scotia, 71, 746
Novaya Zemlya, 608, 609, 748, 752, 761
Nunavut, 17, 49
nursing (hares), 644, 645, 646, 647, 649, 650, 651, 652, 654, 657, 660, 661, 662, 663
Nyctea scandiaca, 527

O

O'Neill, J.J., 37
"oases" (High Arctic), 340, 378, 450, 445
Ob River, 754
oceanography, 27, 42, 48, 207, 763
Ochrolechia frigida, 396
Ochthebius, 122
Oenanthe oenanthe leucorhoa, 530
Oenanthe oenanthe, 527, 530
Oenanthe oenauthe oenathe, 531
Ohmura, A., 337, 341
oil and gas industry, 48, 297, 337, 583
oil lamps, 670, 672
Oithona similis, 220
Okhotsk, 754
Old Crow, 614
"Old Red Sandstone", 57
Old Red Sandstone Continent, 71
Old World, 525, 527
Old World Element, 531
Oldsquaw, 146, 522
Oligocene, 93, 118
oligophagy, 505
Ommanney, Captain Erasmus, 772
Operation Franklin, 10
Ophthalmosaurus, 85
Ordovician, 55
Orient, 751, 752, 753
Orkney Islands, 771
Ormosia, 475
ornithopod dinosaurs - Alaskan, 86
Ortelius, 42, 747, 748, 760
Orthothecium chryseum, 358
Orvig, S., 344
osmeroidid (fish), 86
Osmerus, 101
Osteostraci, 63, 64
ostracoderms, 63, 75
Ostrov Kotel'nyy, 761
Othere (Ottar), 746
Ottawa, 814
Outer Milne Ice Shelf, 236
overgrazing, 639
overwintering, 569, 571, 583, 758, 775, 785
Ovibos moschatus, 143, 146, 367, 590
Oxford University, 387
Oxford University Ellesmere Land Expedition (1935), 809
Oxycoccus microcarpus, 430
oxygen consumption, 490, 495
oxygen isotope values, 237, 240
Oxyria digyna, 114, 115, 647, 654
Oxyria, 117, 457, 657
Oxytropis, 374, 434, 435
ozone hole, 284
ozone layer, 291

P

Pachyospora verrucosa, 396
pachyrhizodontids (fish fossils), 86
Pacific Ocean, 275, 288, 304, 747, 752, 754, 756, 757, 769
Pagophila eburnea, 526, 553

paintings (by DeBray), 789
Palaeozoic, 55, 59, 70, 726
Palearctic, 476, 477, 522, 524, 529, 530, 531
Paleo-Eskimos, 667, 668, 669, 670, 671, 672, 673, 678, 679, 732, 734, 799
Paleo-Indians, 667
paleobiogeography, 125
paleoclimate, 71, 125, 143, 146, 729, 732
paleoecology, 69, 728
paleoenvironments, 101, 141, 143, 437, 726, 729, 739
Paleogene, 124
paleoniscoid (fishes), 82
Paliurus, 117, 118, 123
Paludella squarrosa, 119, 120, 125
Pan-American Element, 531
Pan-boreal Element, 531
Panarctic (company), 320, 321
Pandora Island, 620
Pangnirtung, 387, 731, 738, 819, 821
Pangnirtung Fiord, 808
Pangnirtung Pass, 807, 808, 810, 813
Papaver radicatum, 357, 358, 647, 654
Papaver, 117, 377
parasitoids, 459, 487, 500, 502
Paris, 771, 787, 788
Parker, G.R., 393, 640
Parks Canada, 389
Parnassia, 117
Parr Inlet, 553, 555
Parry Channel, 288, 295, 297, 301, 434, 435
Parry's Rock, 773, 775
Parry, Sir William Edward, 385, 390, 569, 570, 572, 573, 569, 702, 758, 759, 761
parthenogenesis, 457
Parulinae, 530
Patagonia, 162
patterned ground, 354, 395
Payer Harbour, 799, 802
Payer, Lieutenant Julius, 762
Peak 5332, 824
Peary caribou, 6, 146, 367, 369, 371, 373, 378, 579, 584, 596, 600, 609, 610, 612, 615, 616, 618, 619, 622, 623, 624, 625, 680
Peary North Pole Expedition (1908-1909), 793, 794
Peary, Robert E., 25, 762, 763, 797, 799
peat, 174, 355, 429
Pedersen, A., 578
Pedicia hannai antennata, 481
Peel Point, 615
Peel Sound, 57, 610, 619, 620, 621, 760
Peel Sound Formation, 61, 64, 67, 74
Pennsylvania, 793
Pennsylvania Department of Agriculture, 803
Penny, William, 385, 760
Peregrine Falcon, 522
permafrost, 162, 167, 168, 171, 176, 182, 189, 195, 286, 289, 343, 354, 506, 518
Petasites frigidus, 434
"Peterhead" boats, 813
Petermann, A.H., 762
Peterson, Ursula, 393
Petro-Canada Inc., 1
petroleum, 36, 45
Petromyzon (hagfish), 65
Peyton, Ross, 819
phalaropes, 481
Phalaropinae, 531
Phasianidae, 524, 531
Philonotis fontana, 120
Philonotis, 119
Philpots Island, 387
Phipps, Captain Constantine John, 754, 756, 757, 762
Phippsia algida, 354, 357, 358
Phoca hispida, 146, 728
Phoca sp., 141
Phoenix, 760, 787, 789
photosynthesis, 190, 199, 205, 209, 212, 224
Phthiraptera, 459
Phyllodoce coerulea, 432
Physconia muscigena, 396
physiological adaptation (insects), 455
Physocarpus, 116
phytoplankton, 214, 219, 220, 223
Picea, 114, 426, 430
Piceoerpeton, 94, 98
Pijamini, Abraham, 830
pika (carcasses), 163
Pilot, Bob, 817
Pim Island, 793, 797, 799, 801, 802
Pim, Lieutenant B., 771, 774, 775, 779, 780
pine, 429
Pinus strobus, 114
Pinus, 101, 114, 117, 429
Pioneer Peak, 807
Pioneer, 768, 771, 772, 773, 785, 786
Piper Cub aircraft, 821
Pittsburgh, 794
placoderms, 63, 67
plagiomenids, 94, 98, 99
plankton, 218, 226
plant (fossils), 93, 105
plant phenology, 505
Platanus, 93
Plectrophenax nivalis, 528
Pleistocene, 93, 102, 125, 140, 148, 162, 163, 176, 476, 480
Pleistocene vertebrate fossils, 141
plesiosaurs, 85, 86
Pleuropogon sabinei, 436
Pleurozium schreberi, 119, 125
Pleurozium, 119
Pliocene, 93, 118, 122, 123, 162, 355
Plover, 760
plovers, 481
Pluvialis dominica, 525
Pluvialis squatarola, 525
Poa abbreviata, 647
Poa arctica, 358
Podolia (U.S.S.R.), 71
Pogonomyioides segnis, 460
Point Barrow (Alaska), 163, 481, 763
Point Griffiths (Griffiths Point), 782
Point Moss, 232
Point Nias (Nias Point), 780
polar barrens, 356, 357
Polar Bear Pass, 6, 165, 174, 176, 177, 178, 390, 571, 572, 574, 575, 579, 645, 646, 648, 649, 650, 652, 654, 657, 658, 660, 661
Polar Bear Pass National Wildlife Area, 584
polar bear studies, 583
polar bears, 6, 30, 45, 51, 148, 166, 168, 174, 369, 574, 580, 639, 641, 671, 754, 802, 812, 819
Polar Continental Shelf Project (PCSP), 1, 9, 14, 257, 297, 299, 316, 320, 321, 340, 344, 345, 581, 794, 801, 830
polar deserts, 350, 355, 356, 358, 370, 371, 385, 395, 423, 451, 666
Polar Gas Project, 591, 594
polar light-regime, 98
Polar Mountains Expedition (1982), 830
polar pack ice, 304
Polar Sea (U.S. Coast Guard Ship), 344
polar semidesert, 340, 355, 356, 358, 359, 371, 423
Polaris Mine, 192, 199
Polaris, 761

political development, 49
pollen, 268, 317, 460, 728, 729, 739
pollination, 462
pollution, 46, 48
Polo, Marco, 752
Polunin, N., 350, 387, 395
polybranchiaspids, 69
polycotylid (fossil), 85
polynyas, 7, 343, 580, 757, 772, 797
polyphagy, 505
Pond Inlet, 217, 332, 697, 808, 809, 824
poplar, 430
Populus, 429, 430
porolepids, 69
Porsild, A.E., 350
Port Burwell, 283
Portugal, 751, 752, 753
postglacial, 175, 180, 726
Potamogeton, 123
Potentilla fruticosa, 430, 437
pottery, 687, 688
Powell, John M., 390
Powichthys thorsteinssoni, 68
Pre-Dorset culture, 172, 591, 732, 734, 739
Preble, E.A., 517
Precambrian, 59, 726, 759, 807
Presbyornis, 96
Prescott Island, 620
Prince Albert Sound, 592, 593, 594, 595
Prince Albert, 770, 771
Prince Charles Island, 42
Prince of Wales Island, 61, 63, 68, 74, 148, 369, 371, 373, 475, 596, 610, 611, 615, 617, 619, 620, 621, 623
Prince of Wales Strait, 617
Prince Patrick Island, 6, 85, 93, 105, 106, 107, 112, 114, 115, 116, 117, 118, 119, 120, 122, 123, 124, 125, 126, 131, 297, 367, 389, 390, 395, 396, 472, 610, 618, 622, 782
Prince Regent Inlet, 386, 758, 759
Princess Marie Bay, 345, 549
Princess Royal Islands, 614, 615
Prionocera, 472, 474, 477, 478, 480
Procellariidae, 519
Prostrate Shrub Zone, 434, 435
Prostrate Shrub-Herb Transition Zone, 435
Protopteraspis, 74
Protozoa, 205
Prudhoe Bay, 34, 759
Prunus, 426
Pselaphidae, 122
Pseudocalanus, 218, 219, 224, 225, 226
ptarmigan, 141, 163, 569, 778
pteraspidomorphs, 66
pteraspids, 66, 69, 74
Ptolemy, 746
Public Works Canada, 298
Puccinellia angustata, 354, 357
Puccinellia phryganodes, 366, 377
Puccinellia vaginata, 354
Puccinellia, 357, 647
pumice, 180
purple saxifrage, 488, 497, 728
pycnocline, 215, 226
Pythagoras' theorem, 330
Pytheas, 744, 746

Q

Qilalukan, 697
Qilaut Mountain, 821
Quaternary, 122, 125
Quaternary Zoology Collection (Ottawa), 140
Québec, 75, 671
Queen Elizabeth Islands, 6, 81, 105, 106, 124, 281, 288, 295, 297, 299, 301, 303, 304, 308, 309, 310, 311, 316, 319, 320, 321, 341, 356, 367, 371, 374, 422, 435, 436, 445, 476, 600, 612, 615, 616, 617, 619, 621, 622, 624, 625, 645, 662, 744, 761, 763, 764
Queen Maud Gulf, 610, 613, 759
Queen Victoria, 787
quotas (arctic mammals), 595, 641

R

rabbit, 101
Racehorse, 754
radar, 546
radio telemetry, 574, 577, 581, 595
radio-echo sounding (airborne), 236
radiocarbon dating, 143, 163, 164, 180, 686, 691, 718, 732, 734
Rae Strait, 610
Rae, John, 613, 759, 760
raised beaches, 146, 149, 164, 166, 175, 180, 283, 367, 374, 646
Ralston, Sergeant, 803
Rangifer tarandus eogroenlandicus, 609
Rangifer tarandus groenlandicus, 367, 609, 611, 612, 724
Rangifer tarandus pearyi, 146, 367, 609, 611, 622
Rangifer tarandus platyrhynchus, 609
Rangifer tarandus, 590, 608
Rangifer, 146
Ranunculus gmelini, 435
Ranunculus hyperboreus, 118, 436
Ranunculus lapponicus, 118
Ranunculus pedatifidus, 118
Ranunculus, 647
Ravens, 569, 572
Ravine Bay, 550
Rea Point, 299
Read Bay Formation (now Group), 59, 62
Read Island, 593
Red Knot, 525, 531, 544, 546
red-beds, 85
Red-breasted Merganser, 522
Red-throated Loon, 519
refugia, 146, 149
Regosolic Static Cryosols, 355
Regosols, 355
reindeer, 608, 609, 623
remote sensing, 7, 50
Repulse Bay, 697
Rescue, 760
Resolute, 11, 170, 171, 206, 207, 211, 212, 257, 288, 299, 310, 337, 341, 581, 794, 801, 812, 815, 824, 830
Resolute Bay, 192, 574, 613, 615, 705
Resolute Passage, 220, 224
Resolute, 760, 768, 771, 772, 773, 775, 778, 782, 785, 786, 789
resources inventories, 49
Rhacomitrium, 119
Rhagidiidae, 459
rhinoceros, 13, 101
Rhinocerotidae, 101
Rhizocarpon geographicum, 396
Rhododendron lapponicum, 434, 435
Rhynchospora capitallata, 114
Ribes, 426, 437
Rice Strait, 799, 802
Rice, Gail, 1
Rice, Sergeant, 797
Richard Collinson Inlet, 592
Richards Island, 143

Richardson, Dr. John, 759, 760
Rick, A.M., 707
Rijp, Jon, 752
ringed seals, 146, 171, 675, 685, 691, 702, 728
Rissa tridactyla, 526
Ritchie, J.C., 389
Rock Ptarmigan, 524, 572, 573
Rocky Mountains, 308, 476
Rodostethia rosea, 526
Roots, E.F., 584
Rosa acicularis, 430, 437
Ross's Goose, 522
Ross's Gull, 526
Ross, Commander John, 385, 758, 759, 760, 772
Ross, James Clark, 759, 760
Rough-legged Hawk, 522
Royal Air Force Ellesmere Island Expedition, 809
Royal Artillery, 758
Royal Canadian Mounted Police, 33, 274, 584, 616, 633, 725, 812
Royal Navy, 753, 754, 756, 757, 769, 770, 772, 780
Royal Navy Ellesmere Island Expedition, 810
Royal Society (London), 754, 757
Rubus chamaemorus, 432
Rubus strigosus, 437
Ruddy Turnstone, 525, 531, 544, 546
Ruin Island phase, 688, 691, 693
Rumex, 457
Rumicia phlaeas, 457
Russell Island, 610, 619, 620
Russia, 550, 753, 754, 757, 761, 763
Russian fleet, 759
Russian-American Company, 754
Ruysch, Johannes, 42, 748
Rymer Point, 593

S

Sabine, Captain Edward, 758
Sachs Harbour, 353, 614
Sahara, 273
Saiga antelope, 143
Saiga tatarica, 143
Saint Pierre and Miquelon, 788
salamander, 94, 98
salinity, 237, 239, 242, 245, 246
Salix alaxensis, 366, 432, 435, 437
Salix arctica, 358, 359, 366, 377, 432, 434, 435, 438, 462, 488, 491, 497, 502, 505, 506, 647, 657
Salix glauca, 437
Salix herbacea, 366, 435
Salix lanata, 366, 432, 435, 437
Salix niphoclada, 432, 435, 437
Salix polaris, 435
Salix pulchra, 366
Salix reticulata, 435
Salix sitchensis, 505
Salix, 426, 429, 430, 434, 437, 492, 657
salmoniform (fish), 86
Salomonsen, F., 519
salt marshes, 355, 366
Salvelinus alpinus, 728
Salvinia, 93
Sam Ford Fiord, 807, 808, 810
Sambucus, 116
Sami (Lapp), 30, 668
Samoyeds, 608, 668
San Francisco, 757
Sandhill Crane, 525
sandpipers, 481
Sandy Point site, 734
Sangamon interglacial, 268
Santonian - Maestrichtian (age), 86
Sarjeant, W.A.S., 37
satellite imagery, 815, 830
satellites, 322
Savelle, J., 149
Saville, Curt, 824
sawflies, 459, 460
Saxifraga caespitosa, 359, 647
Saxifraga cernua, 358, 647
Saxifraga flagellaris, 647
Saxifraga oppositifolia, 115, 117, 357, 359, 377, 462, 488, 489, 497, 647, 654, 728
Saxifraga tricuspidata, 647
Saxifraga, 356, 377, 462, 657
Scandinavia, 746, 747, 748, 751, 753
Scapanorhynchus (shark-teeth), 88
Schefferville, 343
Schei Point Formation, 82
Schei, Per, 763
Schistidium holmenianum, 358
Schledermann, P., 168
"schlepp effect", 708
Schuster, R.M., 390
Sciadopitys, 124
sciarids, 459
scientific exploration, 754, 756, 761
scientific research, 758
Scindapsites, 117
Scindapsus officinalis, 117
Scolopacidae, 525
Scoresby, William, Jr., 757
Scorpidium scorpioides, 119, 120
Scotland, 549, 550
Scotter, George W., 389, 393, 396
sculptures, 670
sea ice, 6, 48
seabirds, 580
sealing, 592, 593, 753, 756
seals, 6, 7, 28, 30, 141, 162, 164, 166, 168, 172, 174, 175, 178, 666, 669, 697, 703, 705, 707, 708, 752
Seattle, 34
Second Norwegian Arctic Expedition, 387
Second World War, 27, 32, 33, 34, 274, 388, 395, 517, 764, 807
sedge meadows, 424, 640
sedge-moss meadows, 367, 375, 450, 640
sedge-moss tundra, 356
sedges, 174, 354, 430, 432, 436, 438, 480, 639, 647
seeds, 555
SEM (scanning electron microscope), 182
Semipalmated Plover, 525
Senecio congestus, 434
Sermilik Glacier, 808
serviceberry, 430
Severnya Zemlya, 763
Seymour Island, 390
Shackleton's Antarctic expeditions, 807
Shaler Mountains, 593
shamanistic religion, 671
shark teeth, 86
Shell Canada Limited, 1
Shepherdia canadensis, 430
shorebirds, 462, 481, 546, 547, 555, 556, 563, 564
Short-eared Owl, 527
shrew, 101
shrubby cinquefoil, 430
Siberia, 58, 93, 163, 176, 276, 480, 481, 522, 525, 531, 546, 667, 668, 672, 705, 753, 754, 761, 762, 764
Siberia (Angara), 55

Sibir (Soviet icebreaker), 27
Silumiut site, 707
Silurian, 55, 57, 58, 75
Siluro-Devonian, 7
silverberry, 426
Simmons, H.G., 387
Simplocaria, 122
Simpson Strait, 614
Simpson, Thomas, 759
Sirois, Audrey, 1
SIS (Station Information System), 297
Skate (U.S.S.), 27, 797
ski-mountaineering, 809, 810, 815, 824, 830
skijoring, 824
Skogn Lowland, 637
Skraeling Island, 174, 688, 691, 693, 799
sledging, 775, 778, 779, 780, 782, 786, 789
small horse (fossil), 141, 143
smelt-like fish, 101
Smith Island, 616
Smith Sound, 386, 753, 763, 797
Smith, Annie Lorrain, 387
Smoking Hills Formation, 86
Snag, 277
Snow Bunting, 528
snow dens, 576
Snow Geese, 522, 728
snow-houses, 675
Snowblind Bay basin, 57
Snowblind Bay Formation, 62
snowcover, 266, 281
snowflush effect, 357, 374
snowmobiles, 29, 620, 814, 815, 824, 830
snowshoe hares, 644, 662, 663
Snowy Owls, 170, 177, 527, 572, 573, 574, 584
soapberry, 430
social development, 49
Société de Géographie (Paris), 756
sockeye salmon, 505
soil algae, 354
solar (lake), 191
solar radiation, 309, 487
solifluction, 167
Solomons Temple Islands, 389
Somateria mollissima, 522
Somateria spectabilis, 522
Somerset Island, 1, 59, 61, 65, 68, 74, 146, 148, 207, 330, 386,
    393, 395, 475, 610, 610, 611, 615, 617, 619, 620, 621, 623, 702,
    703, 704, 707, 709, 711, 718
Somerset Island Formation, 61, 74
Soper, J.D., 387, 734
Sophia Lake, 188
Sophia Lake Formation, 62
Sophia, 760
Sorbus, 426
Soricinae, 101
South America, 525
South American Element, 531
South Bay, 731
South Pole, 751
South Ward Hunt Ice Shelf, 237
Southampton Island, 387, 390, 393, 395, 396, 472
Southwind Glacier, 819
Southwind Peak, 819
sovereignty, 7, 47, 763
Soviet Arctic (peoples), 30
Soviet Union, 46, 276, 283
Spain, 751, 752
Sparbo-Hardy Lowland, 637
SPASM (surface pressure centre data), 296
Special Sensor Microwave Images (SSM/I), 322
specific electrical conductivity (SEC), 244, 245
Sphagnum, 119, 120, 125
spiders, 444, 456, 459, 462
Spilogona, 459
spirea, 430
Spirea beauverdiana, 430, 437
Spitsbergen, 55, 69, 70, 71, 74, 82, 85, 93, 608, 609, 610, 752, 753,
    754, 756, 757, 758, 761
spring window (for moutaineering), 814, 824
springtails, 444, 454, 455, 459
spruce, 426
Sr-istope dates, 122
St. Helena Island, 746
St. Petersburg, 754
St. Quentin, 788
St. Roch, 26
stable isotope tracing, 230, 250
staging areas, 546, 555, 563, 564, 565
Starnes Fiord, 616
Starunia, 162
starvation, 546, 641
Station Nord, 27
Stefansson, Vilhjalmur, 31, 37, 594, 744, 763, 764
Stellaria humifusa, 366
Steltner, Hermann, 824
Stenkul Fiord, 92, 94
Stephansson, Sigurdur, 747
Stercorarius longicaudis, 526, 553
Stewart Valley, 808
Stewart, Arch, 1
stone age, 672
stone tools, 669, 687
stoneflies, 454
storms, 283
Strabo, 746
"Strait of Anian", 747, 751
Strathcona Fiord, 92, 94, 118
stratification (water), 246, 247
streamlines, 304
Strigidae, 527, 531
Stromness, 771
sub-ice environments, 215
sub-ice fauna, 217
subarctic, 118, 519
submarines, 797
subpolar desert, 350
Summer Island, 143
summer window (for mountaineering), 813
Sunneshine Fiord, 817, 819
Sutcliffe, Antony J., 6
Svalbard reindeer, 609
Sverdrup Basin, 17
Sverdrup Glacier, 637, 640
Sverdrup Inlet, 633, 640
Sverdrup Islands, 25, 763
Sverdrup Lowland, 308, 310, 311, 316, 319, 320, 637
Sverdrup Pass, 166, 574, 575, 583, 645, 646, 647, 649, 650, 651,
    654, 657, 658, 660, 661
Sverdrup, Otto, 25, 387, 762, 799
swan, 101
Sweden, 761
sweet gale, 430
Swinnerton Peninsula, 92, 94
Swiss Bay, 808
Swiss Federal Institute (Munich), 343
Symbos cavifrons, 143
"Symmes Hole", 751
sympatry, 525

T

taeniodont, 94
Taimyr, 66
Talbot, 787
"talik", 189, 192, 200
Tamir, 763
Tanquary Fiord, 345, 390, 809, 810
taphonomy, 123
Taxodium, 115
Taylor Island, 574
Taylor, W.E., 705
technology, 50
Tedrow, J.C.F., 350
Tegethoff, 762
Teloschistes arcticus ("*Bonera* aurantiaca"), 390
temperature, 45, 311
Tener, John S., 1, 373, 390, 582, 616
tent rings, 712
terrestrial arthropods, 444, 445
territorial activities, 548, 563
Terror, 760, 769
Tertiary, 45, 91, 93, 101, 105, 117, 118, 124, 125
Tetraoninae, 524, 531
Thames River, 771
Thamnolia subuliformis, 357, 396
The Alpine Journal, 810
"The Birds of Canada", 517, 572
The Canadian Alpine Journal, 809, 810
The Dinosaur Project, 85
The Inglefield Mountains Expedition (1980), 830
The Mitre, 819
The Wash, 549
thelodont (fossils), 62, 63, 64, 67, 69, 75
thermocline, 198, 199
theropod (dinosaurs) - Alaskan, 86
Thick-billed Murre, 527
Thomson, J.W., 389, 390
Thorndike Peaks, 830
Thorndike Peaks Expedition (1987), 830
Thorne, Robert, 752
Thorsteinsson, R., 11, 58, 63, 65, 390
Thraupinae, 530
Thuidium abietinum, 120
Thuja occidentalis, 114
Thuja, 117
Thule (dog skull), 172
Thule (houses), 168, 174, 175, 178, 670, 673, 686, 688, 704
Thule (snow knife), 178
Thule Air Base, 27
Thule culture, 591, 672, 673, 675, 677, 678, 679, 680, 681, 685, 686, 687, 691, 693, 695, 697, 702, 705, 706, 707, 708, 711, 712, 718, 733, 734, 738, 740, 802
"Thule" (land), 744
Thule sites, 699, 702, 703, 704, 706, 716, 733
Thule whaling, 709
Thumb Mountain Formation, 192
tidal mixing, 216
tides, 214, 215, 219, 224
Tikera Bay, 734
Tilman, H.W., 808
Timmia, 119
Tipula (Arctotipula) besselsi, 474, 475, 477, 478
Tipula (Arctotipula), 477, 478
Tipula (Vestiplex) arctica, 475, 476
Tipula carinifrons, 456
Tipula hewitti, 475
Tipula sacra, 476
Tipula suttoni, 477
Tipula tribulator, 477
Tipulidae, 459, 471, 472, 474, 476, 477, 478, 480, 481
Titanic, 27
Todds Island, 614
Toll, E., 763
Tomenthypnum nitens, 119
Tomenthypnum, 120
toothed birds (hesperornithiforms), 86
Tortella fragillis, 119
tortoise, 98
Tortula ruralis, 357
Totnes Road, 808, 819
Toulon, 769
tourism, 48, 569, 813, 816
toxicology, 48, 291
Tozer, E.T., 11, 82, 111
trading posts, 593, 594, 596, 598
Trafton, Steve, 810
Transpolar Current, 759
Transport Canada, 298
transportation, 48
trapping, 593, 599, 601, 753
traquairaspids, 69, 74
Treaty of Tordesillas, 751
treeline, 124, 304, 423, 430, 437, 438, 516, 517, 519, 522, 524, 667
Trent, 758
Triassic, 82, 85
Trichocera columbiana, 460
trilophosaur, 82
Trochilidae, 530
Tromsö, 761
trout, 101
Truelove Inlet, 571
Truelove Lowland, 167, 341, 367, 489, 633, 635, 639, 640, 641
Truelove Valley, 635, 640
Tsar Alexander I, 754
Tsar Peter the Great, 754
Tsuga, 101
Tuckerman, Edward, 386
Tuktoyaktuk, 11, 19
tundra, 350, 355
Tundra Swan, 522
tunnit, 672, 673
turnstones, 548, 549, 550, 553, 555, 556, 559, 560, 562, 563, 564, 565
turtles, 86, 94, 99
twin flower, 430
Twin Otter aircraft, 619, 797, 813, 815, 830
Tyrannidae, 530

U

U.S. Academy of Sciences, 285
U.S. Defense Meteorological Satellite Program, 322
Ulmus, 115
umiaks, 672, 680, 699, 704
Ungava, 332, 333, 335, 387, 390, 434, 671
Union Bay, 772
United Kingdom, 550
United States, 32, 85, 304, 308, 322, 757, 801, 802, 803
University of Bristol, 71
University of Colorado, 390
University of Ottawa, 58, 71
University of Windsor, 340
University of Wisconsin, 390, 393
university students, 583
Upernavik, 771
Uria aalge, 527
Ursus arctos, 612
Ursus maritimus, 754
Uummannaq (Greenland), 163

V

Vaccinium uliginosum, 366, 435
Vaccinium, 426
Vaigach, 763
Valais (Switzerland), 308
Van Hauen Pass, 390
Vancouver, 310, 812
Vancouver Island, 757
varanid lizard, 98
vascular plant (fossils), 114, 116
vascular plants, 358, 422, 423
Vega, 762
vegetation zones, 51
Verbena, 116
Verne, Jules, 751, 788
Vibe, C., 623
Victoria and Albert Mountains, 308, 810
Victoria Island, 146, 173, 281, 319, 330, 366, 369, 371, 373, 390, 393, 430, 450, 525, 573, 574, 590, 591, 592, 593, 594, 595, 596, 598, 599, 600, 601, 610, 611, 612, 612, 613, 614, 615, 616, 617, 624, 687, 759
Victoria Strait, 760
Victoria, 759
Victory, 759
Vincent, J.-S., 143
Vireonidae, 530
Virginia Glacier Expedition (1977), 819
Viscount Melville Sound, 206, 297, 320, 610, 611, 617, 619, 620, 758
Vivian Island, 620
Vladivostok, 757
vocalization (hares), 650
"voluntary hypothermia", 501, 502, 505
Voyce, Jackie, 1

W

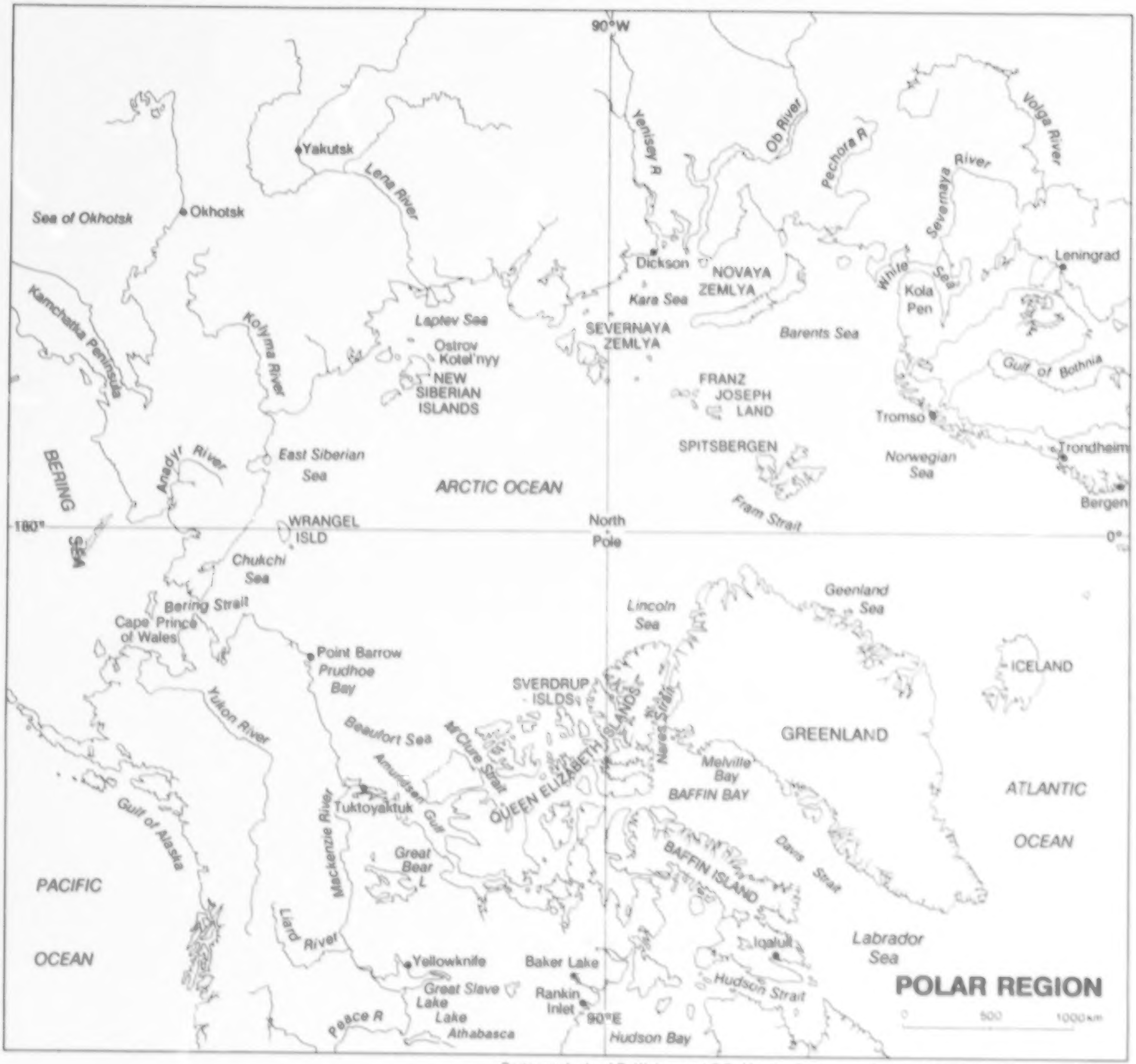
Wade Point, 797
Wager Plateau, 423
Walewski, Count, 771
Walker Bay, 593
Walker, Dr. David, 386
walrus (bone), 164
walrus (ivory harpoon head), 178
walruses, 146, 168, 175, 178, 584, 697, 752
Ward Hunt Ice Shelf, 229, 230, 232, 237, 238, 241, 247, 248, 251
Ward Hunt Island, 236, 237, 242, 248, 389, 390
Warren, Rupert, 393
wasps, 459
Water Pipit, 528
waterfowl, 680, 691, 734
Waterloo, battle of, 756
weather, 547, 553
Weber, J.R., 1
Weber, W.A., 389, 390
Wellington Bay, 601
Wellington Channel, 758, 769, 773, 787
Wenlockian (geological horizon), 57
West Greenland Current, 600
West Simpson (weather base), 334
West Spitsbergen current, 756
West Ward Hunt Ice Shelf, 242, 249
wetlands, 429, 430, 432, 434, 435, 436, 438, 476, 726, 728
Weyprecht, Lieutenant Karl, 762
whale (carcass), 163
whale (skeletons), 176
whale bone houses, 673
whale bone scavenging, 717
whales, 45, 148, 164, 168, 170, 180, 673, 687, 709, 733, 752
whaling, 28, 33, 34, 590, 673, 675, 680, 695, 696, 697, 699, 704, 705, 706, 707, 708, 710, 711, 715, 716, 717, 718, 753, 756, 757, 772
whaling gear (Thule), 699, 702
Whalley, Ted, 808, 824
White Glacier, 396
White Island, 754
White Sea, 746
White-tailed Eagle, 522
Wiegela, 116, 117
wildlife, 277, 582, 590, 591
wildlife population fluctuations, 591
wildlife surveys, 594
willow, 429, 492, 502, 669
Willow Ptarmigan, 524
windchill factor, 553, 556, 563
winds (warm, dry), 308
Windward, 762
winter clothing, 686
winter gnat, 460
Winter Harbour, 283, 385, 472, 758, 773
Winter Island, 387
winter studies, 569
Wisconsin, 149
Wisconsin glaciation, 143, 146, 268, 356, 610
WISP (synthetic wind statistics), 296
wolves, 170, 576, 577, 584, 657
Wollaston Peninsula, 593, 595
wolverines, 163, 580
wolves, 30, 176, 177, 369, 577, 579, 601, 602, 612, 639
Wonders, William C., 1
Wong, P.Y., 389
wood bison, 149
Wood Creek, 550
Wood, D.W., 393
wooden tools, 686
Woodsia, 647
woolly mammoth, 143, 163
woolly rhinoceros, 162, 163
woolly-bear caterpillar, 487, 488
Woolwich Basin, 768
Wordie, J.M., 807
World Climate Research Program, 50
worms, 174
Wrangel Island, 763
wuttagoonaspid arthrodire, 70

Y

Yakutsk, 754
Yellowknife, 337
Yelverton Bay, 230, 232, 830, 831
Yenesey River, 762
Ymer (Soviet icebreaker), 27
Young Island, 610, 619
Young, S.B., 350, 423
Yukon Territory, 17, 71, 140, 176, 269, 277, 332, 369, 531, 614
yunnanolepid antiarch, 70

Z

Zeno, Nicolo, 747
"Zonda", 308
zooplankton, 7, 224, 206, 208, 214, 219, 225, 226


90°W
Yakutsk
Lena River
Sea of Okhotsk
Okhotsk
Yenisey R
Ob River
Pechora R
Severnaya River
Volga River
Dickson
NOVAYA ZEMLYA
Kara Sea
White Sea
Kola Pen
Leningrad
Kamchatka Peninsula
Kolyma River
Laptev Sea
SEVERNAYA ZEMLYA
Barents Sea
Ostrov Kotel'nyy
NEW SIBERIAN ISLANDS
FRANZ JOSEPH LAND
Gulf of Bothnia
Tromso
Trondheim
SPITSBERGEN
Norwegian Sea
Bergen
BERING SEA
Anadyr River
East Siberian Sea
ARCTIC OCEAN
Fram Strait
180°
WRANGEL ISLD
North Pole
0°
Chukchi Sea
Bering Strait
Cape Prince of Wales
Lincoln Sea
Geenland Sea
Point Barrow
Prudhoe Bay
ICELAND
SVERDRUP ISLDS
QUEEN ELIZABETH ISLANDS
Nares Strait
Yukon River
Beaufort Sea
M'Clure Strait
GREENLAND
Amundsen Gulf
Melville Bay
BAFFIN BAY
Tuktoyaktuk
ATLANTIC OCEAN
Gulf of Alaska
Mackenzie River
Great Bear L
BAFFIN ISLAND
Davis Strait
PACIFIC OCEAN
Liard River
Iqaluit
Labrador Sea
Yellowknife
Baker Lake
Great Slave Lake
Rankin Inlet
Hudson Strait
POLAR REGION
Peace R
Lake Athabasca
90°E
Hudson Bay
0
500
1000km

Cartography by J.R. Weber and E.R. Maahs, Geological Survey of Canada, Geophysics Division

Canadian Museum
of Nature

Musée canadien
de la nature

Canada